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A nationwide assessment has been made of the quantity and quality of urban storm flow emanating from combined sewers, storm sewers, and unsewered portions of all 248 urbanized areas and other urban areas in the United States. Available control alternatives and their associated costs were also determined. Continuous simulation runs using one year of hourly data were made to determine the attainable level of pollution control with a specified availability of storage volume and treatment rate in five cities: Atlanta, Denver, Minneapolis, San Francisco, and Washington, DC. This procedure was used to derive generalized equations relating pollution control to storage and treatment. These results were combined into a simple optimization model which determined the optimal mix of storage and treatment for any feasible level of control for any city. Then the nationwide assessment is presented. The results indicate annual costs ranging from $297 million for 25 percent pollution control to $[illegible],029 million for 85 percent pollution control. The corresponding initial capital investment ranges from $2,476 million for 25 percent control to $41,968 million for [illegible] percent control. These costs can be reduced significantly if stormwater pollution control is integrated with dry-weather quality control and wet-weather quantity control. Also, the relative impact of wet-weather versus dry-weather flows is illustrated for a case study of Des Moines, Iowa.

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NATIONWIDE EVALUATION OF COMBINED SEWER OVERFLOWS AND URBAN STORMWATER DISCHARGES

Volume II: Cost Assessment and Impacts

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This report has been reviewed by the Municipal Environmental Research Laboratory, US Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the US Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The US Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

A nationwide evaluation of combined sewer overflows and stormwater discharges can be used by policy makers in allocating resources among various environmental management programs. This report estimates, for urban areas in the United States, the population and area served by type of sewerage system; the quantity and quality of stormwater discharges from these areas; the cost for various levels of control either as a single purpose program or as a multiple purpose program wherein some of the costs are assigned to dry-weather sewage treatment and/or urban storm drainage; and evaluates receiving water impacts for a test city, Des Moines, Iowa.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

A nationwide assessment has been made of the quantity and quality of urban storm flow emanating from combined sewers, storm sewers, and unsewered portions of all 248 urbanized areas and other urban areas in the United States. Available control alternatives and their associated costs were also determined. Continuous simulation runs using one year of hourly data were made to determine the attainable level of pollution control with a specified availability of storage volume and treatment rate in five cities: Atlanta, Denver, Minneapolis, San Francisco, and Washington, DC. This procedure was used to derive generalized equations relating pollution control to storage and treatment. These results were combined into a simple optimization model which determined the optimal mix of storage and treatment for any feasible level of control for any city. Then the nationwide assessment is presented. The results indicate annual costs ranging from $297 million for 25 percent pollution control to $5,029 million for 85 percent pollution control. The corresponding initial capital investment ranges from $2,476 million for 25 percent control to $41,900 million for 85 percent control. These costs can be reduced significantly if stormwater pollution control is integrated with best management practices and integrated into a multi-purpose program.

The entire results from this project are contained in the three volumes listed below:

1. American Public Works Association and University of Florida,
   Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges: Volume I, Executive Summary,
   USEPA, 1977.
2. Heaney, J. P., W. C. Huber, M. A. Medina, Jr., M. P. Murphy, S. J. Nix, and S. M. Hasan,
   Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges: Volume II, Cost Assessment and Impacts,
   USEPA, 1977.
3. Sullivan, R. H., M. J. Manning, and T. M. Kipp,
   Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges: Volume III, Characterization of Discharges,
   USEPA, 1977.

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Richard Field of USEPA provided invaluable overall guidance and detailed critical review of findings throughout the study.

Numerous persons at the University of Florida contributed to this effort. Michael Fladmark and Dave Wolters coded and checked the input data for the 248 urbanized areas. Henry Malec did the initial work of deriving the isoquant equations. Gordon Quesenberry developed the storm event definition. Typing of the numerous drafts and final report was done by Ms. Mary Polinski who deserved special credit for her patience and persistence in completing the manuscript.

SECTION I

CONCLUSIONS

During the past decade, much effort has been expended in identifying and analyzing the wet-weather pollution control problem. The initial concern with combined sewer overflows expanded to consideration of stormwater runoff in general. This study assesses the costs of controlling wet-weather pollution to varying degrees. A key question is what is the relative importance of various sources of wet-weather pollution and how does wet-weather pollution control compare to dry-weather pollution control? Also, what is its impact on receiving water?

Control of wet-weather pollution is distinctly different than the traditional dry-weather problem. In wet-weather pollution control, one would normally use a mix of storage and treatment, not treatment alone. Thus, new techniques are needed to determine optimal mixes of storage and treatment. Numerous effectiveness criteria for wet-weather control have been used, e.g., number of overflows, percent runoff control, percent BOD control. For wet-weather control, the most critical impact on the receiving water does not necessarily occur under low flow conditions. How should the critical conditions be defined? Basic questions of this nature arose throughout the study because it is such a relatively new area of concern. Thus, the final estimate could vary widely if some of these assumptions are changed. However, the approach is a fairly general one and assumptions are stated explicitly. Thus, the interested reader can refine the estimates as better information becomes available. The remainder of this section presents conclusions. The following section on recommendations will focus on data gaps and related matters.

DEMOGRAPHIC CHARACTERISTICS OF THE URBANIZED AREAS

Urban areas in this study have been taken as the 248 urbanized areas defined by the Bureau of the Census of the US Department of Commerce in the 1970 census and other urban areas. The 248 urbanized areas defined in 1970 are generally characterized as having:

- a central city or urban core of 50,000 or more inhabitants;

- closely inhabited surroundings, consisting of incorporated places of 100 housing units or more; and small unincorporated parcels with population densities of 1,000 inhabitants per square mile or more (386 per square km); and

- other small unincorporated areas that may eliminate enclaves, square up the geometry of the urbanized area or provide a linkage to other enumeration districts fulfilling the overall criteria within 1 1/2 miles (2.5 km) of the main body of the urbanized area.

All 248 urbanized areas in the United States were analyzed in varying levels of detail. Population density distribution functions were developed for 50 urbanized areas. These results were extrapolated to the other 198 urbanized areas. Land use information was derived based on a statistical analysis of 106 cities. The results for all USEPA regions and the entire US are shown in Table I-1, Demographic Characteristics of the Urban Areas. A total of almost 150 million people live in urbanized areas in the United States at an overall average population density of 5.1 persons per acre (12.6 persons per ha). Urbanized areas, as defined, are about 46.2 percent undeveloped as estimated in Table I-2, Land Use Distribution for the Urban Areas in the US. The distribution of the developed land uses is approximately as follows:

Residential	58.4
Industrial	14.8
Commercial	8.6
Other	18.2
Total	100.0

Information on population and area served by combined sewerage systems were provided by APWA. The population and area served by storm sewers and in the unsewered area were estimated as residuals. All areas with a developed population density of less than five persons per acre were assumed to be unsewered. The results, shown in Table I-3, Land Use by Type of Sewerage System, indicate that about 14.4 percent of the urban area is served by combined sewers, 38.3 percent by storm sewers, and the balance of the developed area is unsewered. Table I-4, Population by Type of Sewerage System indicates that 25.2 percent of urban population is served by combined sewer systems, 52.1 percent by storm sewer systems, and the remaining 22.7 percent is unsewered. Table I-5, Population Density by Type of Sewerage System indicates nationwide average developed population densities of 16.73 (41.30), 13.00 (32.09), and 4.59 (11.33) persons per acre (persons per ha) in combined, storm and unsewered areas and an overall average developed population density of 9.56 persons per acre (23.6 persons per ha).

TABLE I-1 DEMOGRAPHIC CHARACTERISTICS OF THE URBAN AREAS

EPA REG	STATE ID	1000 ACRES	1970 POP 1000	POP AVE PD
1	CT	559.	2344.	4.19
1	ME	235.	507.	2.15
1	MA	966.	4813.	4.98
1	NH	125.	417.	3.34
1	RI	162.	826.	5.09
1	VT	35.	143.	4.14
TL REG 1		2082.	9050.	4.35
2	NJ	1479.	6372.	4.31
2	NY	830.	15611.	18.92
TL REG 2		2309.	21983.	9.52
3	DE	75.	395.	5.27
3	DC	39.	757.	19.26
3	MD	403.	3005.	7.46
3	PA	1350.	8433.	6.24
3	VA	569.	2933.	5.15
3	WV	162.	680.	4.21
TL REG 3		2598.	16203.	6.24
4	AL	683.	2011.	2.94
4	FL	1275.	5463.	4.29
4	GA	697.	2768.	3.97
4	KY	304.	1687.	5.54
4	MS	276.	987.	3.57
4	NC	651.	2287.	3.51
4	SC	344.	1233.	3.59
4	TN	719.	2307.	3.21
TL REG 4		4949.	18745.	3.79
5	IL	1189.	9221.	7.75
5	IN	778.	3371.	4.33
5	MI	1092.	6559.	6.01
5	MN	696.	2527.	3.63
5	OH	1714.	8021.	4.68
5	WI	688.	2911.	4.23
TL REG 5		6157.	32610.	5.30
6	AR	301.	962.	3.20
6	LA	328.	2406.	7.34
6	NM	175.	711.	4.07
6	OK	599.	1740.	2.91
6	TX	2546.	8934.	3.51
TL REG 6		3948.	14753.	3.74
7	IA	536.	1615.	3.01
7	KS	328.	1485.	4.53
7	MO	710.	3278.	4.61
7	NE	184.	913.	4.96
TL REG 7		1758.	7291.	4.15
8	CO	335.	1737.	5.18
8	MT	82.	372.	4.53
8	ND	50.	274.	5.51
8	SD	68.	297.	4.38
8	UT	231.	854.	3.69
8	WY	49.	201.	4.08
TL REG 8		816.	3735.	4.58
9	AK	49.	147.	2.99
9	AZ	384.	1408.	3.67
9	CA	2828.	18142.	6.41
9	HI	106.	638.	6.01
9	NV	120.	396.	3.31
TL REG 9		3487.	20731.	5.95
10	ID	85.	387.	4.58
10	OR	305.	1403.	4.60
10	WA	546.	2475.	4.54
TL REG 10		935.	4265.	4.56
TL U.S.		29037.	149366.	5.14

TABLE I-2 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA REG	STATE ID	LAND USE AS % OF TOTAL AREA					
		UNDV	RES	COMM	INDL	OTH	TOTAL
1	CT	50.0	29.2	4.3	7.4	9.1	100.0
1	ME	69.9	17.6	2.6	4.5	5.5	100.0
1	MA	44.2	32.6	4.8	8.3	10.2	100.0
1	NH	56.9	25.2	3.7	6.4	7.8	100.0
1	RI	42.1	33.8	5.0	8.6	10.5	100.0
1	VT	49.5	29.5	4.3	7.5	9.2	100.0
AV REG 1		49.3	29.6	4.4	7.5	9.2	100.0
2	NJ	48.5	30.1	4.4	7.6	9.4	100.0
2	NY	23.8	44.5	6.6	11.3	13.9	100.0
AV. REG. 2		39.6	35.3	5.2	8.9	11.0	100.0
3	DE	40.8	34.6	5.1	8.8	10.8	100.0
3	DC	3.8	56.2	8.3	14.2	17.5	100.0
3	MD	28.4	41.8	6.2	10.6	13.0	100.0
3	PA	36.3	37.2	5.5	9.4	11.6	100.0
3	VA	46.9	31.0	4.6	7.9	9.7	100.0
3	WV	47.5	30.7	4.5	7.8	8.6	100.0
AV. REG 3		37.7	36.4	5.4	9.2	11.3	100.0
4	AL	61.3	22.6	3.3	5.7	7.0	100.0
4	FL	50.0	29.2	4.3	7.4	9.1	100.0
4	GA	50.5	28.9	4.3	7.3	9.0	100.0
4	KY	39.2	35.5	5.2	9.0	11.1	100.0
4	MS	54.7	26.4	3.9	6.7	8.2	100.0
4	NC	55.2	26.2	3.9	6.6	8.2	100.0
4	SC	54.3	26.7	3.9	6.8	8.3	100.0
4	TN	59.4	23.7	3.5	6.0	7.4	100.0
AV. REG 4		53.6	27.1	4.0	6.9	8.4	100.0
5	IL	28.7	41.6	6.1	10.5	13.0	100.0
5	IN	47.1	30.9	4.6	7.8	9.6	100.0
5	MI	37.3	36.6	5.4	9.3	11.4	100.0
5	MN	54.1	26.8	3.9	6.8	8.3	100.0
5	OH	45.3	32.0	4.7	8.1	10.0	100.0
5	WI	49.7	29.4	4.3	7.4	9.2	100.0
AV REG 5		42.4	33.6	5.0	8.5	10.5	100.0

TABLE I-2 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA REG	STATE ID	LAND USE AS % OF TOTAL AREA					
		UNDV	RES	COMM	INDL	OTH	TOTAL
6	AR	58.8	24.1	3.5	6.1	7.5	100.0
6	LA	39.1	35.6	5.2	9.0	11.1	100.0
6	NM	50.1	29.2	4.3	7.4	9.1	100.0
6	OK	61.1	22.7	3.3	5.8	7.1	100.0
6	TX	56.0	25.7	3.8	6.5	8.0	100.0
AV REG 6		55.3	26.1	3.8	6.6	8.1	100.0
7	IA	60.4	23.1	3.4	5.9	7.2	100.0
7	KS	46.4	31.3	4.6	7.9	9.8	100.0
7	MO	46.7	31.1	4.6	7.9	9.7	100.0
7	NE	43.0	33.3	4.9	8.4	10.4	100.0
AV REG 7		50.4	28.9	4.3	7.3	9.0	100.0
8	CO	41.9	33.9	5.0	8.6	10.6	100.0
8	MT	46.5	31.3	4.6	7.9	9.7	100.0
8	ND	39.2	35.5	5.2	9.0	11.1	100.0
8	SD	47.8	30.5	4.5	7.7	9.5	100.0
8	UT	53.7	27.1	4.0	6.9	8.4	100.0
8	WY	50.0	29.2	4.3	7.4	9.1	100.0
AV REG 8		46.5	31.2	4.6	7.9	9.7	100.0
9	AK	60.1	23.3	3.4	5.9	7.3	100.0
9	AZ	53.7	27.0	4.0	6.9	8.4	100.0
9	CA	35.4	37.7	5.6	9.6	11.8	100.0
9	HI	36.0	37.4	5.5	9.5	11.6	100.0
9	NV	57.1	25.0	3.7	6.3	7.8	100.0
AV REG 9		38.6	35.9	5.3	9.1	11.2	100.0
10	ID	45.9	31.6	4.7	8.0	9.8	100.0
10	OR	45.8	31.6	4.7	8.0	9.9	100.0
10	WA	46.3	31.4	4.6	7.9	9.8	100.0
AV REG 10		46.1	31.5	4.6	8.0	9.8	100.0
AV U.S.		46.2	31.4	4.6	8.0	9.8	100.0

TABLE I-3 LAND USE BY TYPE OF SEWERAGE SYSTEM

AREA SERVED BY TYPE OF SYSTEM

1000 ACRES

EPA REG	STATE ID	UNDV	COMB	STORM	UNSEW	TOTAL
1	CT	279.4	51.4	82.7	145.4	558.8
1	ME	164.4	44.4	0.0	26.5	235.3
1	MA	426.9	101.8	160.5	276.8	966.0
1	NH	71.1	31.7	0.0	22.1	124.9
1	RI	68.3	21.8	23.9	48.2	162.2
1	VT	17.1	7.9	0.0	9.6	34.6
TL REG 1		1027.1	259.1	267.0	528.5	2081.8
2	NJ	717.6	26.5	301.5	433.4	1479.0
2	NY	197.1	245.6	241.1	145.9	829.7
TL REG 2		914.8	272.1	542.6	579.2	2308.7
3	DE	30.6	6.8	17.2	20.3	75.0
3	DC	1.5	12.7	25.1	0.0	39.3
3	MD	114.5	0.0	190.5	97.9	402.8
3	PA	489.5	89.3	432.0	339.5	1350.4
3	VA	266.8	28.0	154.3	120.0	569.2
3	WV	76.7	57.6	3.5	23.7	161.6
TL REG 3		979.6	194.5	822.6	601.4	2598.2
4	AL	418.8	0.0	105.1	159.1	683.0
4	FL	637.4	0.4	311.6	325.3	1274.7
4	GA	352.1	60.2	102.7	181.8	696.9
4	KY	119.4	9.6	88.1	87.4	304.4
4	MS	151.2	0.0	51.5	73.5	276.2
4	NC	359.1	0.0	113.7	178.1	650.9
4	SC	186.7	0.0	62.1	94.8	343.6
4	TN	427.0	25.7	98.8	167.5	718.9
TL REG 4		2651.8	95.9	933.6	1267.4	4948.6
5	IL	341.9	306.9	218.5	321.9	1189.1
5	IN	366.3	167.9	57.3	186.6	778.1
5	MI	406.8	233.8	156.0	295.4	1092.0
5	MN	376.6	47.9	98.1	172.9	695.5
5	OH	775.7	211.2	237.6	489.0	1713.6
5	WI	341.9	31.8	144.4	170.0	688.2
TL REG 5		2609.2	999.5	912.0	1635.8	6156.6

TABLE I-3 LAND USE BY TYPE OF SEWERAGE SYSTEM

AREA SERVED BY TYPE OF SYSTEM

1000 ACRES

EPA REG	STATE ID	UNDV	COMB	STORM	UNSEW	TOTAL
6	AR	177.0	11.6	30.1	82.4	301.0
6	LA	128.2	0.0	130.0	69.5	327.7
6	NM	87.4	0.0	38.3	48.9	174.7
6	OK	365.8	0.0	87.6	145.3	598.8
6	TX	1426.8	5.1	489.3	624.8	2546.0
TL REG 6		2185.2	16.7	775.3	970.9	3948.2
7	IA	323.8	8.9	76.5	126.7	535.9
7	KS	151.9	21.3	66.8	87.6	327.5
7	MO	331.6	163.6	29.8	185.4	710.4
7	NE	79.1	29.6	19.4	55.8	183.9
TL REG 7		886.4	223.3	192.6	455.5	1757.7
8	CO	140.5	1.8	98.1	94.5	334.9
8	MT	38.2	0.0	24.2	19.8	82.2
8	ND	19.5	1.0	18.5	10.8	49.7
8	SD	32.7	0.7	15.0	20.1	68.4
8	UT	124.1	0.0	46.3	60.8	231.2
8	WY	24.6	0.0	11.3	13.4	49.3
TL REG 8		379.5	3.4	213.3	219.3	815.6
9	AK	29.6	0.7	6.7	12.1	49.2
9	AZ	206.2	0.0	80.7	97.1	384.0
9	CA	1002.0	67.1	1050.4	708.7	2828.1
9	HI	38.3	0.0	36.9	31.1	106.2
9	NV	68.3	2.8	17.3	31.1	119.6
TL REG 9		1344.4	70.6	1191.9	880.1	3487.0
10	ID	38.8	0.0	21.9	23.8	84.5
10	OR	139.8	32.7	45.7	86.7	305.0
10	WA	252.6	79.9	68.8	144.3	545.6
TL REG 10		431.2	112.6	136.5	254.8	935.1
TL U.S.		13409.	2248.	5987.	7393.	29037.

TABLE I-4 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	POPULATION SERVED (1000 PERSONS) COMB	STORM	UNSEW	TOTAL
1	CT	692.	979.	673.	2344.
1	ME	372.	0.	135.	507.
1	MA	1155.	2404.	1254.	4813.
1	NH	286.	0.	131.	417.
1	RI	346.	278.	202.	826.
1	VT	69.	0.	74.	143.
TL	REG 1	2919.	3661.	2470.	9050.
2	NJ	405.	4473.	1495.	6372.
2	NY	9603.	5369.	639.	15611.
TL	REG 2	10007.	9842.	2134.	21983.
3	DE	83.	210.	101.	395.
3	DC	400.	357.	0.	757.
3	MD	0.	2545.	460.	3005.
3	PA	1354.	5802.	1277.	8433.
3	VA	298.	2143.	492.	2933.
3	WV	515.	42.	122.	680.
TL	REG 3	2651.	11100.	2451.	16203.
4	AL	0.	1238.	773.	2011.
4	FL	6.	4075.	1385.	5465.
4	GA	590.	1156.	1022.	2768.
4	KY	116.	1187.	384.	1687.
4	MS	0.	596.	391.	987.
4	NC	0.	1315.	972.	2287.
4	SC	0.	697.	536.	1233.
4	TN	312.	1249.	746.	2307.
TL	REG 4	1024.	11512.	6209.	18745.
5	IL	6109.	1582.	1530.	9221.
5	IN	1845.	715.	811.	3371.
5	MI	3293.	1885.	1382.	6559.
5	MN	593.	1218.	716.	2527.
5	OH	2647.	3429.	1944.	8021.
5	WI	679.	1272.	960.	2911.
TL	REG 5	15166.	10101.	7343.	32610.

TABLE I-4 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	POPULATION SERVED (1000 PERSONS) COMB	STORM	UNSEW	TOTAL
6	AR	80.	345.	537.	962.
6	LA	0.	2012.	394.	2406.
6	NM	0.	485.	226.	711.
6	OK	0.	1150.	590.	1740.
6	TX	101.	6031.	2801.	8934.
TL REG 6		181.	10023.	4549.	14753.
7	IA	252.	754.	609.	1615.
7	KS	254.	768.	463.	1485.
7	MO	1635.	254.	1389.	3278.
7	NE	419.	260.	234.	913.
TL REG 7		2559.	2036.	2695.	7291.
8	CO	36.	1260.	441.	1737.
8	MT	0.	256.	116.	372.
8	ND	10.	197.	67.	274.
8	SD	8.	183.	106.	297.
8	UT	0.	589.	265.	854.
8	WY	0.	126.	75.	201.
TL REG 8		55.	2610.	1070.	3735.
9	AK	10.	93.	44.	147.
9	AZ	0.	989.	419.	1408.
9	CA	1663.	13493.	2986.	18142.
9	HI	0.	499.	139.	638.
9	NV	41.	217.	139.	396.
TL REG 9		1713.	15291.	3727.	20731.
10	ID	0.	232.	155.	387.
10	OR	427.	574.	402.	1403.
10	WA	903.	871.	701.	2475.
TL REG 10		1330.	1677.	1258.	4265.
TL U.S.		37606.	77853.	33906.	149366.

TABLE I-5 POPULATION DENSITY BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	POPULATION DENSITY (PERSONS/ACRE)			
		COMB	STORM	UNSEW	AVER
1	CT	13.07	11.84	4.63	8.39
1	ME	8.36	0.0	5.12	7.15
1	MA	11.34	14.98	4.53	8.03
1	NH	9.02	0.0	5.02	7.75
1	RI	15.85	11.60	4.20	8.79
1	VT	8.75	0.0	7.73	8.19
AV REG 1		11.27	13.71	4.67	8.58
2	NJ	15.27	14.83	3.05	8.37
2	NY	39.10	22.27	4.38	20.68
AV REG 2		36.78	18.14	3.68	15.77
3	DE	12.23	12.23	4.98	8.01
3	DC	31.40	14.24	0.0	20.02
3	MD	0.0	13.36	8.70	10.82
3	PA	15.17	13.43	3.76	9.80
3	VA	10.63	13.89	4.10	9.70
3	WV	8.44	12.04	5.16	8.01
AV REG 3		13.63	13.49	4.08	10.01
4	AL	0.0	11.78	4.86	7.61
4	FL	10.20	13.08	4.24	8.58
4	GA	9.81	11.25	5.62	8.03
4	KY	12.03	13.06	4.40	9.12
4	MS	0.0	11.57	5.32	7.90
4	NC	0.0	11.56	5.06	7.84
4	SC	0.0	11.22	5.66	7.86
4	TN	12.16	12.64	4.45	7.90
AV REG 4		10.68	12.33	4.90	8.16
5	IL	19.91	7.24	4.75	10.88
5	IN	10.99	12.48	4.34	8.19
5	MI	14.08	12.08	4.68	9.57
5	MN	12.37	12.41	4.14	7.92
5	OH	12.53	14.03	3.98	8.55
5	WI	21.32	8.81	5.65	8.81
AV REG 5		15.17	11.08	4.89	9.10
6	AR	6.93	11.47	6.52	7.76
6	LA	0.0	15.47	5.68	12.06
6	NM	0.0	12.66	4.62	8.15
6	OK	0.0	13.12	4.06	7.07
6	TX	19.78	12.33	4.48	7.98
AV REG 6		10.87	12.93	4.68	8.37
7	IA	28.38	9.85	4.81	7.81
7	KS	11.93	11.50	5.29	8.45
7	MO	10.00	8.52	7.49	8.65
7	NE	14.17	13.41	4.19	8.71
AV REG 7		11.06	10.57	5.02	8.37
8	CO	19.03	12.84	4.66	8.93
8	MT	0.0	10.57	5.86	8.06
8	ND	10.67	10.67	6.18	9.06
8	SD	12.23	12.23	5.28	8.32
8	UT	0.0	12.72	4.37	7.08
8	WY	0.0	11.16	5.62	8.16
AV REG 8		15.00	12.24	4.88	8.56
9	AK	13.75	13.75	3.66	7.50
9	AZ	0.0	12.26	4.32	7.92
9	CA	24.79	12.85	4.21	9.03
9	HI	0.0	13.55	4.46	9.39
9	NV	14.38	12.50	4.46	7.72
AV REG 9		24.26	12.83	4.23	9.68
10	ID	0.0	10.58	6.52	8.07
10	OR	13.04	12.57	4.64	8.50
10	WA	11.31	12.65	4.86	8.05
AV REG 10		11.82	12.29	4.94	8.06
AV U.S.		16.73	13.00	4.59	9.56

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RUNOFF ANALYSIS

An examination of precipitation patterns led to the division of the country into five zones for purposes of analysis with the Corps of Engineers' STORM model: Pacific Coast, Rocky Mountain, Midwest and Texas, South and Southeast, and Northeast. STORM was run on a representative city for each of these regions: San Francisco, Denver, Minneapolis, Atlanta, and Washington, DC. Results from these runs were used in developing the nationwide assessment methodology and also used to calibrate the elementary technique used for runoff prediction for the 248 urbanized areas.

Annual wet-weather runoff was generated using a runoff coefficient that is a function of imperviousness which in turn is a function of population density. Table I-6, Annual Wet-Weather Runoff for Combined, Storm, and Unsewered Areas indicates average runoff of 16.5 inches (41.9 cm) per year, 14.8 inches (37.6 cm) per year, and 10.8 inches (27.4 cm) per year from an average precipitation of 33.4 inches (84.8 cm) per year in combined, storm and unsewered urban areas, respectively. Dry-weather flow is a function of population density on the basis of 100 gallons per person-day (379 liters per person-day). Table I-7, Annual Dry-Weather Flow for Combined, Storm, and Unsewered Areas illustrates runoff magnitudes by USEPA region and for the US as a whole.

Average annual dry-weather flow (DWF) is significantly greater than average wet-weather flow (WWF) only in the arid areas of USEPA regions 8 and 9. The heavily urbanized regions 2 and 3 produce the highest dry-weather flows (although above average precipitation partially offsets these values). However, in most parts of the country, dry-weather flows represent 30-50 percent of the total (wet plus dry) runoff from urban areas.

PREDICTION OF URBAN RUNOFF QUALITY

Analysis of available urban runoff quality data indicates a great number of disaggregated urban runoff studies from which it is highly difficult to draw meaningful conclusions as to pollutant loading rates. For instance, there are no known studies in which both surface and effluent data have been gathered simultaneously. In addition, there is a wide variation in the manner in which data are reported (e.g., "average" concentrations) and in the amount of related information provided about the catchment areas (e.g., population density).

On the basis of the available data, pollutant loading estimates were developed for wet weather for BOD_5, suspended solids, volatile solids, total phosphate (PO_4) and total nitrogen (N), and derived as functions of precipitation, land use and population density, the latter only for residential land use. Other land uses are commercial, industrial and open. These estimates indicate that, for the same population density, loads from combined sewered areas are approximately four times higher than those from separate sewered areas. Furthermore, higher population

TABLE I-6 ANNUAL WET-WEATHER RUNOFF

EPA REG	STATE ID	IN/YR ANNL. PRECP	WET-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
1	CT	43.7	18.8	18.1	13.4	16.1
1	ME	43.5	16.0	0.0	13.6	15.2
1	MA	43.6	17.6	19.6	13.2	16.4
1	NH	41.0	15.4	0.0	13.5	14.7
1	RI	40.0	18.5	16.5	12.0	15.0
1	VT	35.0	13.1	0.0	12.6	12.8
AV REG 1		41.1	17.2	18.9	13.2	16.0
2	NJ	42.8	19.1	19.4	12.2	15.9
2	NY	38.1	25.8	21.4	11.0	21.1
AV REG 2		40.5	25.2	20.3	11.9	18.2
3	DE	45.0	19.0	19.0	14.2	17.0
3	DC	41.0	24.8	18.2	0.0	20.7
3	MD	42.0	0.0	18.5	13.1	16.9
3	PA	41.0	17.6	18.2	11.4	15.9
3	VA	42.9	16.9	18.7	13.2	16.6
3	WV	41.0	15.4	18.6	13.8	15.2
AV REG 3		42.1	17.4	18.4	12.2	16.3
4	AL	55.8	0.0	23.4	17.7	20.3
4	FL	56.5	22.7	24.9	17.1	21.3
4	GA	46.5	18.1	19.2	15.3	17.1
4	KY	42.3	17.9	18.1	12.5	15.8
4	MS	54.5	0.0	22.1	17.5	19.6
4	NC	46.0	0.0	18.6	14.6	16.4
4	SC	46.7	0.0	19.1	15.3	17.0
4	TN	48.3	19.4	20.5	14.6	17.3
AV REG 4		49.6	18.5	21.7	15.8	18.6
5	IL	35.0	16.6	11.6	10.3	13.4
5	IN	37.2	14.7	15.1	10.9	13.3
5	MI	31.0	13.6	12.9	9.5	11.9
5	MN	26.0	10.5	10.6	7.4	9.1
5	OH	37.2	14.6	15.6	10.2	12.9
5	WI	29.7	14.5	10.8	9.2	10.5
AV REG 5		32.7	14.8	12.9	9.8	12.3

TABLE I-6 ANNUAL WET-WEATHER RUNOFF

EPA REG	STATE ID	IN/YR ANNL. PRECP	WET-WEATHER FLOW (INCHES PER YEAR)			
			COMB	STORM	UNSEW	AVER
6	AR	48.0	15.0	20.6	16.4	17.4
6	LA	56.0	0.0	27.5	17.4	24.1
6	NM	9.0	0.0	3.6	2.5	3.1
6	OK	32.7	0.0	14.2	9.7	11.7
6	TX	31.0	24.7	14.2	10.1	12.3
AV REG 6		35.3	17.9	16.2	10.7	13.4
7	IA	31.3	18.0	12.1	9.7	11.1
7	KS	33.0	14.1	13.2	10.4	12.1
7	MO	36.8	14.2	13.3	12.7	13.5
7	NE	26.5	11.4	11.5	7.7	9.7
AV REG 7		31.9	14.0	12.6	10.8	12.2
8	CO	14.5	6.1	5.8	4.0	5.1
8	MT	14.0	0.0	5.4	4.3	5.0
8	ND	21.0	8.3	8.3	6.9	7.8
8	SD	25.0	10.4	10.4	7.9	9.1
8	UT	15.0	0.0	6.3	4.4	5.3
8	WY	15.0	0.0	5.9	4.7	5.3
AV REG 8		17.4	7.5	6.4	4.7	5.6
9	AK	30.0	13.1	13.1	8.6	10.6
9	AZ	9.0	0.0	3.1	2.2	2.7
9	CA	17.2	11.3	5.9	4.6	5.7
9	HI	23.0	0.0	9.9	6.9	8.7
9	NV	5.5	2.9	1.6	1.2	1.5
AV REG 9		16.9	10.9	5.8	4.3	5.5
10	ID	11.0	0.0	4.2	3.5	3.9
10	OR	39.3	17.2	16.8	12.2	14.7
10	WA	30.3	12.0	15.5	10.6	12.3
AV REG 10		26.9	13.5	14.1	10.5	12.4
AV U.S.		33.4	16.5	14.8	10.8	13.4

TABLE I-7 ANNUAL DRY-WEATHER FLOW

EPA REG	STATE ID	IN/YR ANNL. PRECP	DRY-WEATHER FLOW (INCHES PER YEAR)			
			COMB	STORM	UNSEW	AVER
1	CT	43.7	18.1	15.9	6.2	11.3
1	ME	43.5	11.2	0.0	6.9	9.6
1	MA	43.6	15.2	20.1	6.1	12.0
1	NH	41.0	12.1	0.0	8.0	10.4
1	RI	40.0	21.3	15.6	5.6	11.8
1	VT	35.0	11.8	0.0	10.4	11.0
AV REG 1		41.1	15.1	18.4	6.3	11.5
2	NJ	42.8	20.5	19.9	4.6	11.2
2	NY	38.1	52.5	29.9	5.9	33.2
AV REG 2		40.5	49.4	24.4	5.0	21.2
3	DE	45.0	16.4	16.4	6.7	12.0
3	DC	41.0	42.2	19.1	0.0	26.9
3	MD	42.0	0.0	18.0	6.3	14.0
3	PA	41.0	20.4	18.0	5.1	13.2
3	VA	42.9	14.3	18.7	5.5	13.0
3	WV	41.0	12.0	16.2	6.9	10.8
AV REG 3		42.1	18.3	18.1	5.5	13.5
4	AL	55.8	0.0	15.8	6.5	10.2
4	FL	56.5	19.1	17.6	5.7	11.5
4	GA	46.5	13.2	15.1	7.6	10.8
4	KY	42.3	16.2	18.1	5.9	12.3
4	MS	54.5	0.0	15.6	7.1	10.6
4	NC	46.0	0.0	15.5	7.3	10.5
4	SC	46.7	0.0	15.1	7.6	10.6
4	TN	48.3	16.3	17.0	6.0	10.6
AV REG 4		49.6	14.4	16.6	6.6	11.0
5	IL	35.0	26.8	9.7	6.4	14.6
5	IN	37.2	14.8	16.8	5.8	11.0
5	MI	31.0	18.9	16.2	6.3	12.9
5	MN	26.0	16.6	16.7	5.6	10.6
5	OH	37.2	16.8	19.4	5.3	11.5
5	WI	29.7	28.7	11.8	7.6	11.3
AV REG 5		32.7	20.4	14.9	6.0	12.4

TABLE I-7 ANNUAL DRY-WEATHER FLOW

EPA REG	STATE ID	IN/YR ANNL PRECP	DRY-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER.
6	AR	48.0	9.3	15.4	8.8	10.4
6	LA	56.0	0.0	20.8	7.6	16.2
6	NM	9.0	0.0	17.0	6.2	11.0
6	OK	32.7	0.0	17.6	5.5	10.0
6	TX	31.0	26.6	16.6	6.0	10.7
AV REG 6		35.3	14.6	17.4	6.3	11.2
7	IA	31.3	38.1	13.2	6.5	10.2
7	KS	33.0	16.0	15.5	7.1	11.4
7	MO	36.8	13.4	11.4	10.1	11.6
7	NE	26.5	19.0	18.0	5.6	11.7
AV REG 7		31.9	15.4	14.2	8.0	11.2
8	CO	14.5	26.8	17.3	6.3	12.0
8	MT	14.0	0.0	14.2	7.9	11.4
8	ND	21.0	14.3	14.3	8.3	12.2
8	SD	25.0	16.4	16.4	7.1	11.2
8	UT	15.0	0.0	17.1	5.9	10.7
8	WY	15.0	0.0	15.0	7.6	11.0
AV REG 8		17.4	21.4	16.4	6.6	11.5
9	AK	30.0	18.5	18.5	4.9	10.1
9	AZ	9.0	0.0	16.5	5.8	10.6
9	CA	17.2	33.3	17.3	5.7	13.4
9	HI	23.0	0.0	18.2	6.0	12.6
9	NV	5.5	19.3	16.8	6.0	10.4
AV REG 9		16.9	32.6	17.2	5.7	13.0
10	ID	11.0	0.0	14.2	8.8	11.4
10	OR	39.3	17.5	16.9	6.2	11.4
10	WA	30.3	15.2	17.0	6.5	11.4
AV REG 10		26.9	15.9	16.5	6.6	11.4
AV U.S.		33.4	22.5	17.5	6.2	12.8

densities in combined sewered areas will increase the ratio even more because loadings are assumed to be an increasing function of population density.

NATIONWIDE QUALITY ASSESSMENT

Annual BOD_5 loads were calculated for the 248 urbanized areas for both wet and dry-weather conditions, the latter under the assumption of 0.17 pounds per person-day (0.08 kg per person-day). Annual loads for other parameters may be easily calculated for any urbanized area from information provided in Section V.

The national summary is shown in Table I-8, Dry-Weather BOD Loadings and Table I-9, Wet-Weather BOD Loadings. Loading rates for untreated dry-weather flow are higher than for wet-weather flow. However, if 85 percent secondary treatment is assumed for dry-weather BOD generation, wet-weather loads are seen to be one third of the total residual loadings in urban areas. Moreover, BOD loadings from combined sewered areas are comparable to loads due to secondary effluent.

COST ASSESSMENT METHODOLOGY

A generalized method for evaluating the optimal mix of storage and treatment for any desired level of pollutant control was presented. This method can be used for any city in the United States to obtain a first approximation of control costs. Five cities (Atlanta, Denver, Minneapolis, San Francisco, and Washington, DC) were used in the more detailed analysis. The effects of treatment plant efficiency and first flush are included.

An evaluation was made of the relative desirability of using a mix of storage with either primary treatment or secondary treatment. The basic tradeoff to be evaluated is whether primary treatment is sufficiently less expensive than secondary treatment to offset its lower removal efficiency which necessitates treating a much larger amount of flow to effect an equivalent BOD removal. The results indicate that a primary type of facility is preferable up to BOD removals of about ten percent. A secondary facility is preferable for higher levels of control.

The annual average percent runoff control and the annual number of overflow events were correlated to permit the reader to use either criterion as an effectiveness metric. A precipitation event was assumed to terminate following 12 hours of no precipitation.

The final assessment results (annual costs per acre) are shown in Table I-10, Annual Control Costs - Combined Areas, Table I-11, Annual Control Costs - Storm Areas, and Table I-12, Annual Control Costs - Unsewered Areas.

TABLE I-8 DRY-WEATHER BOD LOADINGS

EPA REG	STATE ID	IN/YR ANNL. PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
1	CT	43.7	836.	736.	288.	521.
1	ME	43.5	519.	0.	318.	444.
1	MA	43.6	704.	931.	281.	554.
1	NH	41.0	560.	0.	368.	481.
1	RI	40.0	984.	721.	261.	546.
1	VT	35.0	544.	0.	480.	509.
AV REG 1		41.1	700.	851.	290.	533.
2	NJ	42.8	948.	921.	214.	520.
2	NY	38.1	2428.	1383.	272.	1533.
AV REG 2		40.5	2284.	1126.	229.	979.
3	DE	45.0	760.	760.	309.	553.
3	DC	41.0	1950.	884.	0.	1243.
3	MD	42.0	0.	830.	292.	647.
3	PA	41.0	942.	834.	234.	608.
3	VA	42.9	660.	862.	254.	602.
3	WV	41.0	555.	748.	320.	498.
AV REG 3		42.1	846.	838.	253.	622.
4	AL	55.8	0.	732.	302.	473.
4	FL	56.5	882.	812.	264.	533.
4	GA	46.5	609.	699.	349.	499.
4	KY	42.3	747.	837.	273.	566.
4	MS	54.5	0.	719.	330.	490.
4	NC	46.0	0.	718.	339.	487.
4	SC	46.7	0.	697.	351.	488.
4	TN	48.3	755.	785.	277.	491.
AV REG 4		49.6	663.	766.	304.	507.
5	IL	35.0	1236.	450.	295.	676.
5	IN	37.2	683.	775.	270.	508.
5	MI	31.0	875.	750.	290.	594.
5	MN	26.0	768.	771.	257.	492.
5	OH	37.2	778.	896.	247.	531.
5	WI	29.7	1324.	547.	351.	522.
AV REG 5		32.7	942.	688.	279.	571.

TABLE I-8 DRY-WEATHER BOD LOADINGS

EPA REG	STATE ID	IN/YR ANNL PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR)			
			COMB	STORM	UNSEW	AVER
6	AR	48.0	430.	712.	405.	482.
6	LA	56.0	0.	961.	352.	749.
6	NM	9.0	0.	786.	287.	506.
6	OK	32.7	0.	815.	252.	464.
6	TX	31.0	1228.	766.	278.	496.
AV REG 6		35.3	675.	803.	291.	520.
7	IA	31.3	1763.	612.	299.	473.
7	KS	33.0	741.	718.	328.	525.
7	MO	36.8	621.	529.	465.	537.
7	NE	26.5	880.	833.	260.	541.
AV REG 7		31.9	712.	657.	367.	520.
8	CO	14.5	1238.	798.	290.	555.
8	MT	14.0	0.	657.	364.	525.
8	ND	21.0	662.	662.	384.	563.
8	SD	25.0	759.	759.	328.	516.
8	UT	15.0	0.	790.	271.	495.
8	WY	15.0	0.	693.	349.	506.
AV REG 8		17.4	988.	760.	303.	532.
9	AK	30.0	854.	854.	227.	466.
9	AZ	9.0	0.	761.	268.	492.
9	CA	17.2	1539.	798.	262.	617.
9	HI	23.0	0.	841.	277.	583.
9	NV	5.5	893.	777.	277.	480.
AV REG 9		16.9	1507.	797.	263.	601.
10	ID	11.0	0.	657.	405.	526.
10	OR	39.3	810.	780.	288.	528.
10	WA	30.3	703.	785.	302.	525.
AV REG 10		26.9	734.	763.	307.	526.
AV U.S.		33.4	1039.	807.	285.	594.

TABLE I-9 WET-WEATHER BOD LOADINGS

EPA REG	STATE ID	IN/YR ANNL. PRECP	WET-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
1	CT	43.7	158.6	37.8	31.8	56.9
1	ME	43.5	144.3	0.0	32.1	102.4
1	MA	43.6	152.9	39.7	31.6	56.9
1	NH	41.0	137.8	0.0	31.0	94.0
1	RI	40.0	152.9	34.6	28.8	59.1
1	VT	35.0	117.7	0.0	27.9	68.5
AV REG 1		41.1	149.6	38.7	31.3	62.2
2	NJ	42.8	160.1	39.2	30.1	38.2
2	NY	38.1	190.8	41.1	26.5	95.9
AV REG 2		40.5	187.8	40.1	29.2	64.4
3	DE	45.0	162.2	39.4	33.3	55.5
3	DC	41.0	187.4	37.1	0.0	87.8
3	MD	42.0	0.0	38.0	31.0	35.6
3	PA	41.0	147.0	37.4	28.0	45.1
3	VA	42.9	147.8	38.3	31.8	45.8
3	WV	41.0	137.6	38.6	32.3	104.1
AV REG 3		42.1	147.5	37.8	29.6	47.9
4	AL	55.8	0.0	48.7	41.6	44.4
4	FL	56.5	190.0	51.0	40.8	45.9
4	GA	46.5	159.7	40.4	35.3	58.6
4	KY	42.3	153.2	37.2	30.0	39.8
4	MS	54.5	0.0	46.2	40.5	42.9
4	NC	46.0	0.0	39.0	34.0	36.0
4	SC	46.7	0.0	40.2	35.3	37.2
4	TN	48.3	166.2	42.3	34.7	48.8
AV REG 4		49.6	161.0	44.9	37.2	45.5
5	IL	35.0	133.8	26.3	24.6	64.6
5	IN	37.2	128.6	31.5	26.3	68.8
5	MI	31.0	114.5	27.1	22.7	55.0
5	MN	26.0	90.5	22.3	18.2	30.3
5	OH	37.2	125.3	31.9	24.8	49.3
5	WI	29.7	116.2	23.7	21.5	31.1
AV REG 5		32.7	124.0	27.4	23.5	52.8

TABLE I-9 WET-WEATHER BOD LOADINGS

EPA REG	STATE ID	IN/YR ANNL PRECP	WET-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
6	AR	48.0	138.4	43.2	37.2	48.1
6	LA	56.0	0.0	55.1	40.0	49.9
6	NM	9.0	0.0	7.9	6.6	7.2
6	OK	32.7	0.0	29.4	23.6	25.8
6	TX	31.0	200.1	29.7	24.3	27.5
AV REG 6		35.3	157.3	33.4	25.5	30.2
7	IA	31.3	138.1	26.2	23.0	29.0
7	KS	33.0	121.9	27.9	24.4	37.5
7	MO	36.8	125.2	29.2	28.5	70.3
7	NE	26.5	96.8	23.8	18.9	41.8
AV REG 7		31.9	121.7	27.0	25.0	50.2
8	CO	14.5	50.2	12.4	10.1	11.6
8	MT	14.0	0.0	12.0	10.5	11.3
8	ND	21.0	73.5	17.9	16.1	19.0
8	SD	25.0	90.1	21.9	18.7	21.3
8	UT	15.0	0.0	13.4	10.9	12.0
8	WY	15.0	0.0	12.9	11.3	12.0
AV REG 8		17.4	64.2	13.7	11.5	13.0
9	AK	30.0	111.0	27.0	21.2	26.5
9	AZ	9.0	0.0	7.0	5.8	6.3
9	CA	17.2	88.7	12.5	11.5	14.9
9	HI	23.0	0.0	20.6	16.7	18.8
9	NV	5.5	26.2	4.0	3.5	4.9
AV REG 9		16.9	86.4	12.4	10.9	10.2
10	ID	11.0	0.0	9.3	8.5	8.9
10	OR	39.3	146.0	34.9	29.0	53.8
10	WA	30.3	103.9	32.1	25.3	48.3
AV REG 10		26.9	116.1	29.4	25.0	46.5
AV U.S.		33.4	136.6	30.5	25.9	43.6

TABLE I-10 ANNUAL CONTROL COSTS - COMBINED AREAS

EPA REG	STATE ID	CONTROL COST ($/ACRE)			
		25%	50%	75%	85%
1	CT	33.	102.	321.	510.
1	ME	16.	48.	124.	187.
1	MA	27.	79.	231.	356.
1	NH	16.	46.	130.	196.
1	RI	43.	130.	398.	614.
1	VT	13.	37.	108.	157.
AV REG 1		26.	77.	228.	354.
2	NJ	49.	165.	624.	1068.
2	NY	103.	404.	1606.	2797.
AV REG 2		97.	381.	1510.	2629.
3	DE	29.	88.	246.	374.
3	DC	119.	690.	2010.	3586.
3	MD	0.	0.	0.	0.
3	PA	44.	141.	447.	711.
3	VA	24.	69.	199.	305.
3	WV	17.	48.	136.	206.
AV REG 3		38.	124.	415.	676.
4	AL	0.	0.	0.	0.
4	FL	53.	146.	406.	610.
4	GA	28.	77.	208.	310.
4	KY	27.	79.	228.	350.
4	MS	0.	0.	0.	0.
4	NC	0.	0.	0.	0.
4	SC	0.	0.	0.	0.
4	TN	35.	95.	259.	387.
AV REG 4		30.	82.	225.	336.
5	IL	76.	242.	771.	1225.
5	IN	27.	75.	204.	305.
5	MI	34.	94.	262.	396.
5	MN	21.	56.	153.	229.
5	OH	31.	87.	242.	365.
5	WI	69.	235.	799.	1305.
AV REG 5		46.	137.	414.	650.
6	AR	14.	37.	96.	141.
6	LA	0.	0.	0.	0.
6	NM	0.	0.	0.	0.
6	OK	0.	0.	0.	0.
6	TX	80.	277.	992.	1665.
AV REG 6		35.	111.	371.	608.
7	IA	96.	385.	1542.	2688.
7	KS	26.	71.	193.	287.
7	MO	22.	59.	158.	235.
7	NE	28.	77.	214.	322.
AV REG 7		26.	75.	224.	349.
8	CO	46.	141.	434.	684.
8	MT	0.	0.	0.	0.
8	ND	13.	35.	94.	140.
8	SD	20.	54.	148.	221.
8	UT	0.	0.	0.	0.
8	WY	0.	0.	0.	0.
AV REG 8		32.	95.	286.	445.
9	AK	40.	107.	287.	426.
9	AZ	0.	0.	0.	0.
9	CA	80.	247.	764.	1201.
9	HI	0.	0.	0.	0.
9	NV	14.	36.	96.	142.
AV REG 9		77.	237.	732.	1150.
10	ID	0.	0.	0.	0.
10	OR	48.	128.	343.	509.
10	WA	30.	80.	212.	314.
AV REG 10		35.	94.	250.	370.
AV U.S.		47.	151.	501.	815.

TABLE 7-11 ANNUAL CONTROL COSTS - STORM AREAS

EPA REG	STATE ID	CONTROL COST ($/ACRE)			
		25%	50%	75%	85%
1	CT	27.	79.	230.	352.
1	ME	0.	0.	0.	0.
1	MA	42.	127.	381.	592.
1	NH	0.	0.	0.	0.
1	RI	23.	67.	195.	297.
1	VT	0.	0.	0.	0.
AV REG 1		36.	107.	318.	491.
2	NJ	41.	122.	368.	565.
2	NY	86.	335.	1313.	2271.
AV REG 2		61.	216.	738.	1323.
3	DE	29.	88.	234.	374.
3	DC	35.	105.	311.	481.
3	MD	32.	95.	279.	430.
3	PA	34.	101.	315.	476.
3	VA	35.	103.	306.	473.
3	WV	28.	81.	235.	360.
AV REG 3		33.	100.	289.	461.
4	AL	40.	110.	298.	445.
4	FL	50.	138.	389.	570.
4	GA	31.	84.	228.	340.
4	KY	32.	96.	282.	435.
4	MS	37.	100.	271.	403.
4	NC	32.	86.	253.	348.
4	SC	31.	83.	223.	332.
4	TN	40.	111.	305.	458.
AV REG 4		40.	116.	323.	458.
5	IL	15.	41.	110.	163.
5	IN	32.	88.	243.	364.
5	MI	25.	67.	181.	270.
5	MN	21.	57.	155.	232.
5	OH	40.	112.	315.	477.
5	WI	15.	41.	110.	162.
AV REG 5		25.	69.	189.	283.
6	AR	34.	92.	250.	372.
6	LA	86.	249.	717.	1094.
6	NM	14.	37.	95.	139.
6	OK	31.	88.	232.	347.
6	TX	28.	76.	208.	310.
AV REG 6		38.	105.	292.	440.
7	IA	19.	50.	134.	198.
7	KS	23.	63.	170.	258.
7	MO	18.	49.	130.	193.
7	NE	25.	70.	198.	298.
AV REG 7		21.	56.	152.	226.
8	CO	24.	62.	161.	236.
8	MT	16.	42.	106.	154.
8	ND	13.	35.	90.	140.
8	SD	20.	54.	148.	221.
8	UT	25.	64.	146.	243.
8	WY	19.	49.	126.	183.
AV REG 8		22.	56.	147.	216.
9	AK	40.	107.	287.	426.
9	AZ	11.	30.	77.	112.
9	CA	16.	43.	115.	170.
9	HI	29.	79.	212.	314.
9	NV	6.	16.	41.	60.
AV REG 9		16.	43.	115.	171.
10	ID	13.	32.	82.	119.
10	OR	44.	119.	317.	469.
10	WA	41.	109.	272.	432.
AV REG 10		38.	100.	266.	394.
AV U.S.		32.	94.	279.	434.

TABLE I-12 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	CONTROL COST ($/ACRE) 25%	50%	75%	85%
1	CT	9.	23.	62.	92.
1	ME	10.	27.	72.	107.
1	MA	9.	24.	65.	93.
1	NH	10.	28.	76.	113.
1	RI	8.	20.	52.	77.
1	VT	11.	31.	87.	130.
AV REG 1		9.	24.	63.	94.
2	NJ	7.	19.	50.	72.
2	NY	7.	19.	50.	74.
AV REG 2		7.	19.	50.	72.
3	DE	10.	26.	68.	101.
3	DC	0.	0.	0.	0.
3	MD	9.	23.	61.	90.
3	PA	7.	19.	50.	73.
3	VA	8.	22.	57.	85.
3	WV	10.	26.	68.	101.
AV REG 3		8.	21.	55.	81.
4	AL	14.	34.	87.	127.
4	FL	12.	31.	78.	113.
4	GA	13.	32.	83.	121.
4	KY	8.	21.	57.	84.
4	MS	14.	36.	91.	133.
4	NC	12.	31.	78.	114.
4	SC	13.	32.	83.	121.
4	TN	11.	27.	68.	99.
AV REG 4		12.	31.	78.	114.
5	IL	8.	21.	54.	78.
5	IN	9.	22.	55.	79.
5	MI	8.	19.	49.	70.
5	MN	6.	14.	35.	51.
5	OH	8.	19.	48.	70.
5	WI	8.	21.	53.	77.
AV REG 5		8.	20.	49.	71.
6	AR	15.	39.	100.	146.
6	LA	14.	37.	95.	138.
6	NM	4.	9.	21.	30.
6	OK	7.	18.	46.	66.
6	TX	8.	20.	52.	75.
AV REG 6		9.	22.	56.	82.
7	IA	8.	20.	50.	73.
7	KS	9.	22.	57.	82.
7	MO	15.	38.	100.	147.
7	NE	6.	15.	37.	53.
AV REG 7		11.	27.	70.	103.
8	CO	6.	14.	34.	48.
8	MT	7.	18.	43.	62.
8	ND	6.	17.	42.	62.
8	SD	7.	17.	43.	62.
8	UT	6.	14.	35.	50.
8	WY	7.	18.	45.	64.
AV REG 8		6.	15.	37.	53.
9	AK	8.	19.	48.	69.
9	AZ	3.	7.	18.	25.
9	CA	4.	11.	27.	40.
9	HI	7.	17.	42.	61.
9	NV	2.	4.	10.	14.
AV REG 9		4.	11.	27.	38.
10	ID	6.	16.	38.	55.
10	OR	12.	30.	77.	112.
10	WA	11.	27.	68.	99.
AV REG 10		11.	27.	69.	100.
AV U.S.		8.	22.	56.	81.

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In order to obtain an overall wet-weather pollutant control of, say, 50 percent in a given urbanized area, the optimal strategy is to use a blend of control in the combined, storm, and unsewered portions of the urbanized areas such that the marginal cost of control in each of these three areas is equal. The results are shown in Table I-13, Optimal Percent Control for Specified Overall Percent Control. Knowing this result and the control cost equations for each type of sewerage system in each urbanized area, the optimal cost per acre can be determined as shown in Table I-14, Optimal Annual Cost per Acre for Specified Percent Control. Lastly, the costs per acre are multiplied by the acreage in the combined, storm, and unsewered categories to obtain the final assessment results which are shown in Table I-15, Optimal Annual and Capital Control Costs. The results indicate that, for the entire US, the total annual costs for 25, 50, 75 and 85 percent BOD control are $297, $886, $2,725, and $5,029 millions of dollars per year. Similarly, the initial capital investment for 25, 50, 75 and 85 percent BOD control is $2,476, $7,391, $22,744, and $41,968 millions of dollars based on 85 percent of the present worth of the total annual cost at an assumed interest rate of 8 percent over 20 years. Note that the incremental costs for wet-weather control increase significantly. This is due to the disproportionately larger control units needed to capture the less frequent, larger storms.

An analysis was made of the possibility of cost allocation among wet-weather quality control and dry-weather quality control (with flow equalization) and wet-weather quantity control (with storage required to reduce runoff rates and volumes). The results suggest that significant savings might be realized as shown in Figure I-1, Single Purpose and Multiple Purpose Stormwater Pollution Control Costs for US, which indicates reductions ranging from 70 percent at low control levels to 30 percent at high levels.

In addition to using storage-treatment devices to control wet-weather pollution, other options, popularly called best management practices (BMP's), are available. A related study suggests that significant savings in control costs could be realized if BMP's are used in conjunction with storage-treatment. The estimated costs of control incorporating BMP's are shown in Figure I-1. The savings range from about 50 percent at low levels of control to about 38 percent at higher control levels. Further savings could be realized by allocating some of the cost to other purposes, e.g., street sweeping for aesthetics.

The relationship between tertiary treatment and wet-weather control was examined by finding the percent wet-weather control to initiate prior to using tertiary treatment. Results indicate that about 4 percent of the wet-weather flow problem should be controlled before initiating tertiary treatment control. BOD removal was used as the effectiveness metric. Different results would be obtained using nutrient control as the criterion.

The results of this assessment indicate significantly lower control costs than reported in earlier studies, i.e., the USEPA Needs survey (initial capital cost = $266.1 x 10^9), and the National Commission on Water Quality (NCWQ) study (initial capital cost of $288.6 x 10^9). The NCWQ study

TABLE I-13 OPTIMAL PERCENT CONTROL FOR SPECIFIED OVERALL PERCENT CONTROL.

EPA REG	STATE ID	OPTIMAL PERCENT CONTROL 25% COMB	STORM	UNSEW	50% COMB	STORM	UNSEW	75% COMB	STORM	UNSEW	85% COMB	STORM	UNSEW
1	CT	31.0	3.9	28.6	54.6	29.1	56.1	78.1	54.2	83.5	85.0	85.0	85.0
1	ME	27.9	0.0	3.0	52.0	0.0	28.7	77.7	0.0	54.5	85.0	0.0	85.0
1	MA	34.6	0.0	26.1	60.5	18.4	54.4	84.9	42.2	81.2	85.0	85.0	85.0
1	NH	28.3	0.0	3.7	53.2	0.0	29.5	78.1	0.0	55.3	85.0	0.0	85.0
1	RI	26.5	7.0	32.1	50.5	32.1	59.4	75.1	57.8	85.0	85.0	85.0	85.0
1	VT	32.0	0.0	0.8	56.9	0.0	26.0	81.6	0.0	51.2	85.0	0.0	85.0
2	NJ	29.0	4.0	42.7	48.9	28.1	70.2	77.9	63.0	85.0	85.0	85.0	85.0
2	NY	27.3	2.6	54.8	51.9	27.4	85.0	78.5	54.3	85.0	85.0	85.0	85.0
3	DE	36.7	3.5	27.5	61.1	27.9	54.0	85.0	52.7	81.0	85.0	85.0	85.0
3	DC	25.8	22.9	0.0	48.9	52.8	0.0	72.0	82.8	0.0	85.0	85.0	0.0
3	MD	0.0	16.1	46.2	0.0	40.4	73.0	0.0	70.8	85.0	0.0	85.0	85.0
3	PA	32.2	8.9	42.4	55.7	33.5	70.3	83.3	62.4	85.0	85.0	85.0	85.0
3	VA	44.6	3.8	36.5	69.2	27.8	63.5	85.0	61.5	85.0	85.0	85.0	85.0
3	WV	27.2	0.0	6.5	52.3	9.6	33.1	77.2	33.9	59.3	85.0	85.0	85.0
4	AL	0.0	10.4	36.3	0.0	38.4	62.1	0.0	62.1	85.0	0.0	85.0	85.0
4	FL	40.9	9.9	43.0	64.7	33.9	69.2	85.0	66.6	85.0	85.0	85.0	85.0
4	GA	37.8	0.9	21.4	62.3	25.4	47.4	85.0	51.6	75.1	85.0	85.0	85.0
4	KY	44.0	6.6	37.3	68.4	30.6	64.0	85.0	62.5	85.0	85.0	85.0	85.0
4	MS	0.0	12.1	35.3	0.0	36.2	61.0	0.0	62.5	85.0	0.0	85.0	85.0
4	NC	0.0	11.7	34.7	0.0	35.8	60.4	0.0	61.3	85.0	0.0	85.0	85.0
4	SC	0.0	13.1	33.9	0.0	37.3	59.5	0.0	61.6	85.0	0.0	85.0	85.0
4	TN	39.0	1.2	31.9	63.3	25.2	56.1	85.0	50.9	85.0	85.0	85.0	85.0
5	IL	22.0	28.7	40.8	45.7	52.6	70.4	71.9	83.5	85.0	85.0	85.0	85.0
5	IN	28.4	0.0	19.3	53.7	14.6	46.8	78.3	39.1	73.6	85.0	85.0	85.0
5	MI	28.2	0.8	27.7	52.6	25.9	54.8	77.0	51.0	82.0	85.0	85.0	85.0
5	MN	34.4	0.0	29.5	58.8	23.6	56.2	83.1	47.8	82.7	85.0	85.0	85.0
5	OH	30.6	0.0	28.3	56.3	16.8	56.9	80.7	40.9	84.0	85.0	85.0	85.0
5	WI	18.6	20.4	35.8	39.7	46.7	63.5	63.7	76.6	85.0	85.0	85.0	85.0

TABLE I-13 OPTIMAL PERCENT CONTROL FOR SPECIFIED OVERALL PERCENT CONTROL

		OPTIMAL PERCENT CONTROL											
		25%			50%			75%			85%		
EPA REG	STATE ID	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW
6	AR	55.0	1.4	19.3	80.1	25.5	44.6	85.0	56.8	77.5	85.0	85.0	85.0
6	LA	0.0	13.6	54.3	0.0	37.7	81.6	0.0	71.1	85.0	0.0	85.0	85.0
6	NM	0.0	7.4	41.6	0.0	31.5	67.5	0.0	64.4	85.0	0.0	85.0	85.0
6	OK	0.0	5.8	39.5	0.0	29.4	65.5	0.0	61.7	85.0	0.0	85.0	85.0
6	TX	25.7	10.2	39.1	44.9	34.3	65.3	69.2	64.9	85.0	85.0	85.0	85.0
7	IA	12.7	15.7	36.5	30.9	41.4	63.9	53.7	73.5	85.0	85.0	85.0	85.0
7	KS	38.2	4.2	27.1	62.6	28.7	53.3	85.0	54.4	80.8	85.0	85.0	85.0
7	MO	31.4	0.0	4.2	56.3	24.1	29.8	81.2	49.2	55.4	85.0	85.0	85.0
7	NE	27.7	0.0	28.7	52.5	20.3	56.3	76.8	44.8	83.4	85.0	85.0	85.0
8	CO	24.6	9.6	44.7	45.4	34.0	70.9	73.8	67.3	85.0	85.0	85.0	85.0
8	MT	0.0	16.7	36.7	0.0	41.3	62.3	0.0	67.9	85.0	0.0	85.0	85.0
8	ND	51.4	15.5	32.4	76.1	40.1	58.3	85.0	67.6	85.0	85.0	85.0	85.0
8	SD	44.8	9.5	35.5	68.9	33.6	61.4	85.0	61.8	85.0	85.0	85.0	85.0
8	UT	0.0	6.9	41.9	0.0	30.9	67.8	0.0	64.3	85.0	0.0	85.0	85.0
8	WY	0.0	13.0	36.5	0.0	37.4	62.1	0.0	64.6	85.0	0.0	85.0	85.0
9	AK	36.1	0.3	39.0	60.2	24.4	64.9	85.0	56.4	85.0	85.0	85.0	85.0
9	AZ	0.0	8.6	41.6	0.0	32.8	67.4	0.0	65.1	85.0	0.0	85.0	85.0
9	CA	19.7	13.4	47.6	41.7	38.6	74.4	69.9	71.1	85.0	85.0	85.0	85.0
9	HI	0.0	10.6	46.0	0.0	35.0	71.9	0.0	68.2	85.0	0.0	85.0	85.0
9	NV	30.2	2.5	35.6	54.1	27.0	61.7	80.1	53.5	85.0	85.0	85.0	85.0
10	ID	0.0	16.4	33.7	0.0	41.0	59.1	0.0	65.6	84.5	0.0	85.0	85.0
10	OR	31.9	0.0	27.7	57.0	22.6	54.1	81.6	47.2	80.1	85.0	85.0	85.0
10	WA	32.2	0.0	23.8	57.8	19.7	50.7	82.5	44.3	76.6	85.0	85.0	85.0

TABLE I-14 OPTIMAL ANNUAL COST PER ACRE FOR SPECIFIED PERCENT CONTROL

		OPTIMAL ANNUAL COST PER ACRE											
		25%			50%			75%			85%		
EPA REG	STATE ID	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW
1	CT	43.	11.	10.	127.	32.	30.	371.	95.	87.	510.	332.	92.
1	ME	18.	0.	4.	50.	0.	11.	139.	0.	32.	187.	0.	107.
1	MA	41.	0.	9.	124.	31.	28.	355.	90.	80.	356.	592.	93.
1	NH	19.	0.	4.	53.	0.	12.	147.	0.	34.	196.	0.	113.
1	RI	46.	11.	10.	133.	32.	29.	396.	94.	77.	614.	297.	77.
1	VT	18.	0.	4.	49.	0.	12.	137.	0.	33.	157.	0.	130.
2	NJ	55.	16.	14.	157.	46.	41.	727.	215.	72.	1068.	565.	72.
2	NY	116.	25.	23.	450.	98.	74.	1955.	425.	74.	2797.	2271.	74.
3	DE	48.	12.	11.	135.	33.	30.	374.	94.	87.	374.	374.	101.
3	DC	125.	32.	0.	460.	118.	0.	1696.	436.	0.	3546.	481.	0.
3	MD	0.	22.	20.	0.	63.	56.	0.	233.	90.	0.	430.	90.
3	PA	62.	17.	14.	183.	49.	41.	656.	175.	73.	711.	474.	73.
3	VA	55.	14.	13.	156.	39.	37.	305.	171.	85.	305.	473.	85.
3	WV	19.	0.	5.	53.	14.	13.	149.	41.	37.	206.	360.	101.
4	AL	0.	23.	21.	0.	59.	54.	0.	178.	127.	0.	445.	127.
4	FL	101.	27.	24.	266.	72.	63.	610.	271.	113.	610.	570.	113.
4	GA	47.	12.	11.	125.	32.	29.	310.	90.	83.	310.	340.	121.
4	KY	61.	15.	13.	172.	41.	37.	350.	164.	84.	350.	435.	84.
4	MS	0.	22.	21.	0.	58.	54.	0.	164.	133.	0.	403.	133.
4	NC	0.	19.	17.	0.	49.	45.	0.	135.	114.	0.	348.	114.
4	SC	0.	19.	18.	0.	50.	46.	0.	131.	121.	0.	332.	121.
4	TN	61.	15.	14.	162.	41.	36.	387.	115.	99.	387.	458.	99.
5	IL	66.	15.	15.	198.	46.	46.	667.	154.	78.	1729.	164.	78.
5	IN	31.	0.	7.	87.	21.	19.	233.	57.	52.	305.	364.	79.
5	MI	38.	9.	8.	105.	25.	23.	285.	69.	63.	396.	270.	70.
5	MN	30.	0.	7.	80.	20.	18.	212.	52.	47.	229.	232.	51.
5	OH	39.	0.	9.	113.	29.	25.	306.	77.	67.	365.	477.	70.
5	WI	50.	13.	12.	142.	36.	34.	459.	117.	77.	1305.	162.	77.

TABLE I-14 OPTIMAL ANNUAL COST PER ACRE FOR SPECIFIED PERCENT CONTROL

EPA REG	STATE ID	OPTIMAL ANNUAL COST PER ACRE											
		25%			50%			75%			85%		
		COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW
6	AR	45.	13.	12.	117.	35.	31.	141.	121.	110.	141.	372.	146.
6	LA	0.	53.	44.	0.	148.	121.	0.	609.	138.	0.	1096.	138.
6	NM	0.	7.	6.	0.	18.	16.	0.	63.	30.	0.	139.	30.
6	OK	0.	14.	12.	0.	37.	32.	0.	136.	66.	0.	347.	66.
6	TX	82.	15.	14.	217.	41.	36.	743.	139.	75.	1665.	310.	75.
7	IA	49.	13.	12.	134.	36.	33.	472.	126.	73.	2688.	198.	73.
7	KS	44.	10.	10.	118.	27.	25.	287.	75.	70.	287.	254.	82.
7	MO	28.	0.	7.	76.	18.	18.	202.	47.	47.	235.	193.	147.
7	NE	31.	0.	7.	85.	21.	18.	230.	57.	50.	322.	290.	53.
8	CO	45.	13.	11.	115.	33.	29.	412.	119.	48.	684.	236.	48.
8	MT	0.	12.	11.	0.	30.	27.	0.	81.	62.	0.	154.	62.
8	ND	37.	9.	9.	98.	24.	23.	140.	70.	62.	140.	140.	62.
8	SD	44.	11.	10.	116.	28.	26.	221.	87.	62.	221.	221.	62.
8	UT	0.	12.	11.	0.	31.	27.	0.	110.	50.	0.	243.	50.
8	WY	0.	12.	11.	0.	31.	28.	0.	85.	64.	0.	183.	64.
9	AK	62.	15.	13.	160.	39.	33.	426.	138.	69.	426.	426.	69.
9	AZ	0.	6.	5.	0.	15.	14.	0.	53.	25.	0.	112.	25.
9	CA	63.	10.	10.	169.	27.	27.	607.	99.	40.	1201.	170.	40.
9	HI	0.	17.	14.	0.	44.	38.	0.	162.	61.	0.	314.	61.
9	NV	17.	3.	2.	43.	7.	6.	118.	18.	14.	142.	60.	14.
10	ID	0.	9.	9.	0.	23.	22.	0.	57.	54.	0.	119.	55.
10	OR	63.	0.	13.	169.	40.	35.	445.	106.	93.	509.	469.	112.
10	WA	40.	0.	10.	108.	33.	28.	284.	88.	73.	314.	432.	99.

TABLE I-15 OPTIMAL ANNUAL AND CAPITAL CONTROL COSTS

EPA REG	STATE ID	OPTIMAL ANNUAL CONTROL COST (MILLIONS OF DOLLARS) 25%	50%	75%	85%	OPTIMAL CAPITAL COST (BILLIONS OF DOLLARS) 25%	50%	75%	85%
1	CT	4.6	13.5	39.5	68.6	0.039	0.113	0.330	0.573
1	ME	0.9	2.5	7.0	11.1	0.008	0.021	0.058	0.093
1	MA	6.7	25.4	72.8	157.1	0.056	0.212	0.608	1.311
1	NH	0.7	1.9	5.4	8.7	0.006	0.016	0.045	0.073
1	RI	1.7	5.0	14.6	24.2	0.015	0.042	0.122	0.202
1	VT	0.2	0.5	1.4	2.5	0.002	0.004	0.012	0.021
TL REG 1		14.9	49.0	140.8	272.3	0.124	0.409	1.175	2.273
2	NJ	12.5	35.8	115.2	229.8	0.104	0.299	0.961	1.918
2	NY	37.9	144.9	593.2	1245.2	0.316	1.209	4.951	10.392
TL REG 2		50.4	180.7	708.4	1475.1	0.420	1.508	5.912	12.310
3	DE	0.7	2.1	5.9	11.0	0.006	0.017	0.049	0.092
3	DC	2.4	8.8	32.6	57.2	0.020	0.074	0.272	0.478
3	MD	6.1	17.4	53.2	90.7	0.051	0.146	0.444	0.757
3	PA	17.5	51.5	159.1	293.2	0.146	0.430	1.327	2.447
3	VA	5.2	14.9	45.0	91.8	0.044	0.124	0.376	0.766
3	WV	1.2	3.4	9.6	15.5	0.010	0.028	0.080	0.130
TL REG 3		33.1	98.2	305.4	559.4	0.276	0.819	2.549	4.669
4	AL	5.7	14.8	38.8	66.9	0.047	0.123	0.324	0.558
4	FL	16.3	43.1	121.5	214.6	0.136	0.360	1.014	1.791
4	GA	6.1	16.2	43.1	75.6	0.051	0.135	0.360	0.631
4	KY	3.0	8.5	25.2	49.0	0.025	0.071	0.210	0.409
4	MS	2.7	6.9	18.2	30.5	0.022	0.058	0.152	0.255
4	NC	5.2	13.6	35.7	59.9	0.043	0.114	0.298	0.500
4	SC	2.9	7.5	19.6	32.1	0.024	0.063	0.164	0.268
4	TN	5.4	14.3	37.9	71.7	0.045	0.119	0.316	0.599
TL REG 4		47.2	124.9	340.0	600.3	0.394	1.043	2.838	5.010
5	IL	28.5	85.5	263.6	437.0	0.238	0.714	2.200	3.647
5	IN	6.6	19.4	52.1	86.9	0.055	0.162	0.435	0.725
5	MI	12.9	35.2	96.1	155.4	0.108	0.294	0.802	1.297
5	MN	2.6	8.8	23.3	42.4	0.022	0.074	0.195	0.354
5	OH	12.6	42.8	115.8	224.7	0.105	0.357	0.967	1.875
5	WI	5.5	15.6	44.5	78.1	0.046	0.130	0.371	0.652
TL REG 5		68.7	207.3	595.5	1024.5	0.573	1.730	4.970	8.589

TABLE I-15 OPTIMAL ANNUAL AND CAPITAL CONTROL COSTS

EPA REG	STATE ID	OPTIMAL ANNUAL CONTROL COST (MILLIONS OF DOLLARS) 25%	50%	75%	85%	OPTIMAL CAPITAL COST (BILLIONS OF DOLLARS) 25%	50%	75%	85%
6	AR	1.9	5.0	14.3	24.8	0.016	0.042	0.119	0.207
6	LA	9.9	27.7	88.7	152.2	0.083	0.231	0.740	1.270
6	NM	0.6	1.5	3.9	6.8	0.005	0.012	0.032	0.057
6	OK	3.0	7.9	21.5	40.1	0.025	0.066	0.179	0.334
6	TX	16.5	43.5	116.3	206.9	0.138	0.363	0.987	1.727
TL REG 6		32.0	85.5	244.7	430.7	0.267	0.714	2.058	3.595
7	IA	3.0	8.1	23.1	48.3	0.025	0.068	0.193	0.403
7	KS	2.5	6.5	17.4	30.2	0.021	0.054	0.144	0.252
7	MO	5.9	16.2	43.2	71.5	0.049	0.135	0.360	0.596
7	NE	1.3	4.0	10.7	18.1	0.011	0.033	0.089	0.151
TL REG 7		12.6	34.8	94.2	168.1	0.105	0.291	0.786	1.403
8	CO	2.5	6.2	17.0	28.9	0.020	0.052	0.142	0.241
8	MT	0.5	1.3	3.2	5.0	0.004	0.011	0.027	0.041
8	ND	0.3	0.8	2.1	3.4	0.002	0.006	0.018	0.028
8	SD	0.4	1.0	2.7	4.7	0.003	0.008	0.023	0.039
8	UT	1.2	3.1	8.1	14.3	0.010	0.026	0.068	0.119
8	WY	0.3	0.7	1.8	2.9	0.002	0.006	0.015	0.024
TL REG 8		5.2	13.1	35.0	59.2	0.043	0.109	0.292	0.494
9	AK	0.3	0.8	2.1	4.0	0.002	0.006	0.017	0.034
9	AZ	1.0	2.6	6.7	11.5	0.009	0.021	0.056	0.096
9	CA	21.9	59.2	172.4	287.6	0.183	0.494	1.439	2.400
9	HI	1.1	2.8	7.9	13.5	0.009	0.023	0.066	0.113
9	NV	0.2	0.4	1.1	1.9	0.001	0.004	0.009	0.016
TL REG 9		24.5	65.8	190.1	318.5	0.204	0.549	1.587	2.658
10	ID	0.4	1.0	2.5	3.9	0.003	0.008	0.021	0.033
10	OR	3.2	10.4	27.5	47.8	0.027	0.087	0.230	0.399
10	WA	4.6	14.9	39.2	69.2	0.039	0.124	0.327	0.577
TL REG 10		8.2	26.4	69.2	120.9	0.069	0.220	0.578	1.009
TL U.S.		296.7	885.7	2725.4	5029.0	2.476	7.391	22.744	41.968

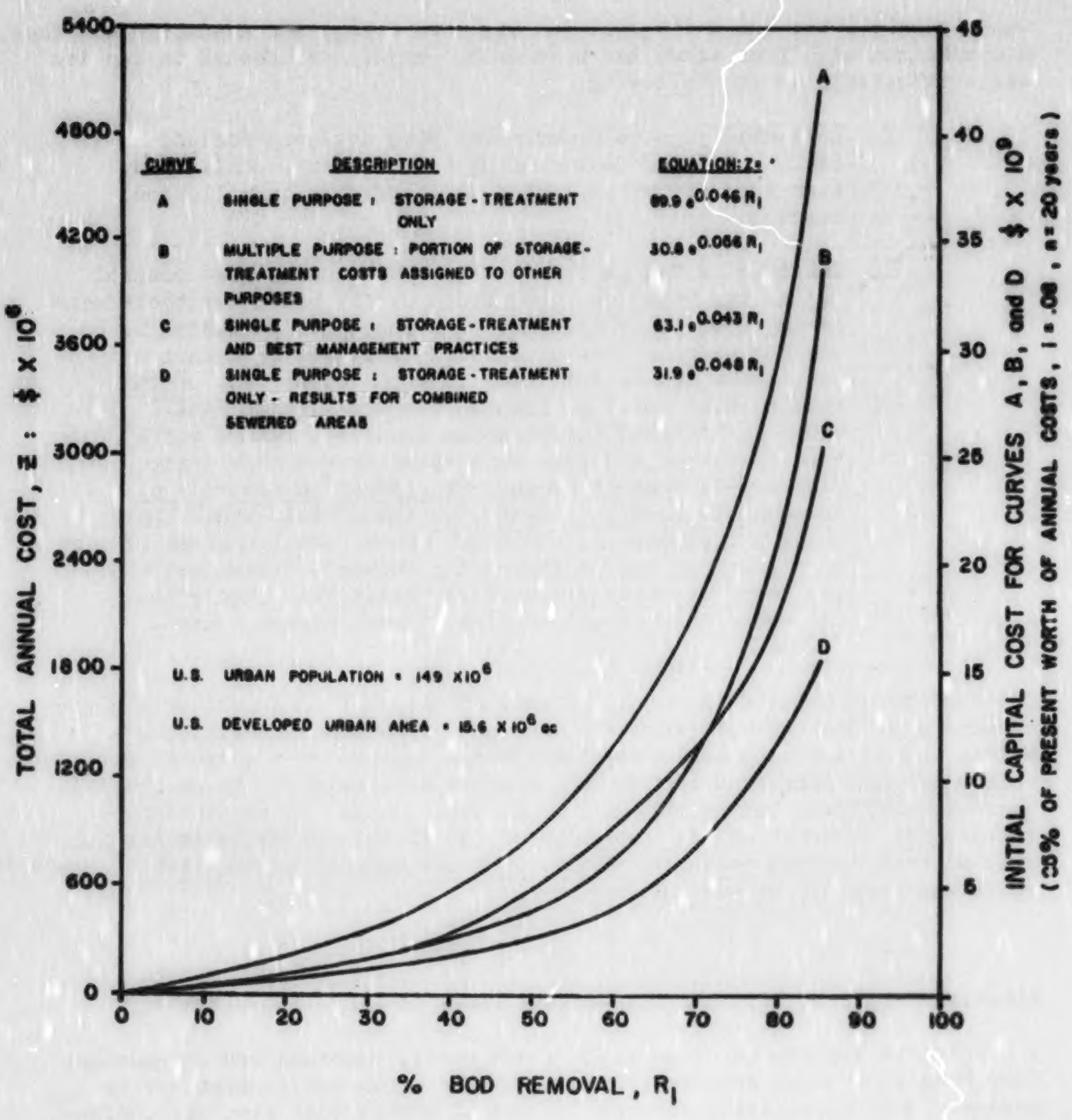


Figure I-1. Single Purpose and Multiple Purpose Stormwater Pollution Control Costs for US

was the only other one which explains its methodology and assumptions. Thus, a comparison with that study has been made. Major differences in results are attributable to the following:

1. Collection System Costs - The NCWQ estimate includes $\$84.0 \times 10^9$ for constructing storm sewers. This study does not view storm sewers as chargeable to pollution control.

2. Choice of a Design Storm - The NCWQ studies used control of the two year, one hour storm as the basis for their mean estimate of control costs. The concept of a design storm was not used in this study because it was felt that a continuous characterization in terms of percent of the runoff which could be treated was more appropriate since no accepted design event condition exists which also specifies a design antecedent dry-weather period. Figure I-2, Overall Percent Precipitation Control vs. Rainfall Intensity, Atlanta, GA (1948-1972) shows that using a frequency of one month would permit capture of 90 percent of the precipitation volume. Sizing for the two year, one hour storm yields relatively little incremented control and requires a much higher control volume.

Only the future will tell which, if any, of the above cost estimating procedures provides the most accurate estimate of national control costs. Within the severe data gathering limitations imposed by a national estimate, this study has attempted to make the results as site specific as possible. Improved estimates can be obtained using local data. In particular, topographic information and knowledge of the numbers of outfalls permits inclusion of pumping costs and analysis of the optimal combination of control units and interceptor sewers.

RELATIVE IMPACT OF WET- AND DRY-WEATHER FLOWS ON RECEIVING WATER

The relative importance of separate storm water, combined and dry-weather flow runoff as waste sources generated by the urban environment may be assessed more effectively through the use of models that simulate continuously in time. Based on an annual simulation of waste inputs to the Des Moines River from the Des Moines metropolitan area, various treatment alternatives are investigated. Minimum dissolved oxygen (DO) cumulative frequency curves indicate that:

1. - During periods of wet weather, the urban runoff contribution of BOD is the most significant among all of the urban BOD sources.

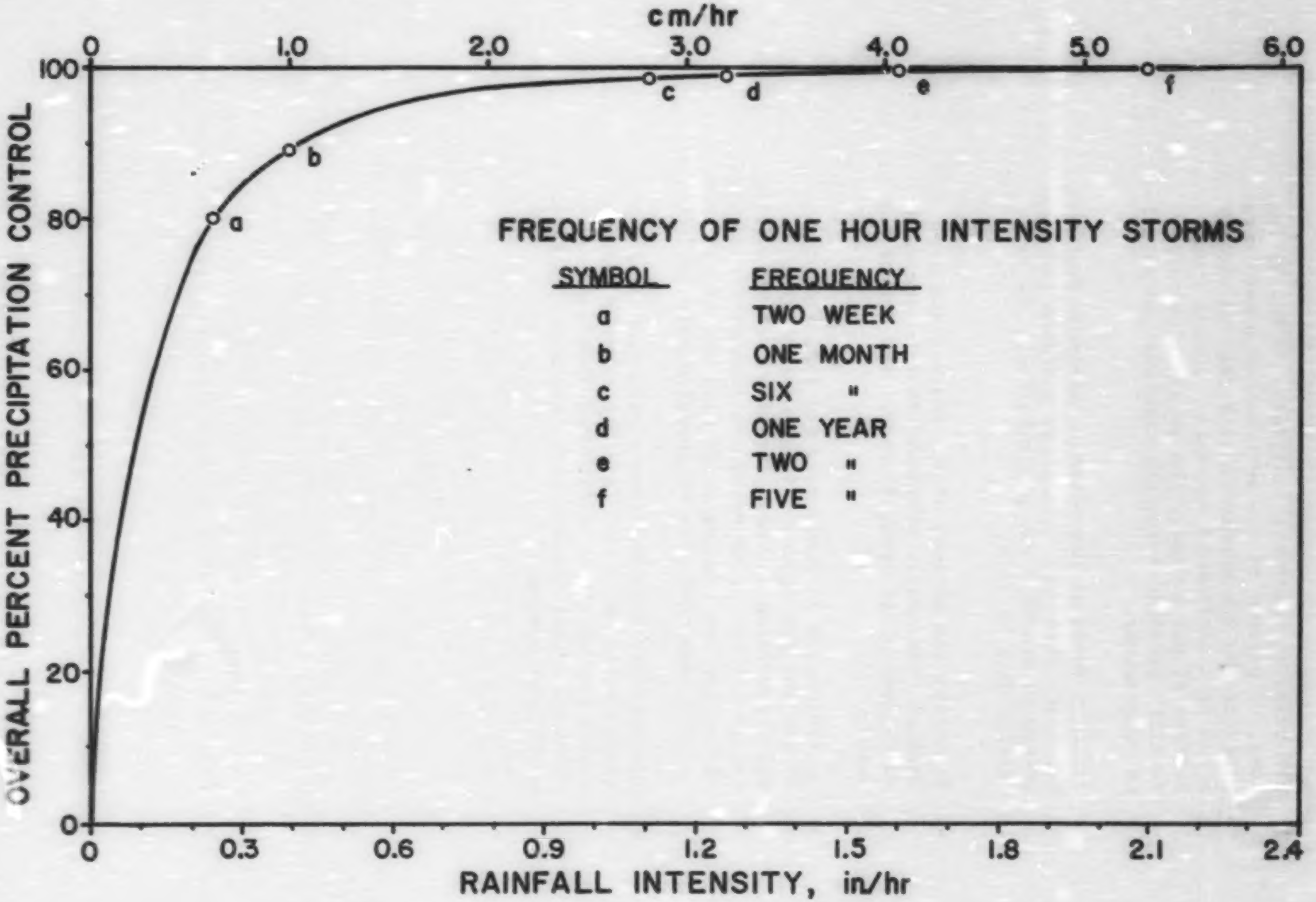


Figure I-2. Overall Percent Precipitation Control vs Rainfall Intensity - Atlanta, GA (1948-1972)

2. For existing treatment facilities in Des Moines, Iowa, 42 percent of the wet-weather events were predicted by the mathematical models to violate a 4.0 mg/l minimum DO standard. During these periods of wet weather, the sewage treatment facility provided secondary treatment to municipal wastewater.

3. During periods of dry weather, effluent from the secondary treatment facilities violated the same stream DO standard two percent of all the dry-weather days in 1968.

4. Combining the effects of wet weather and dry weather, the models predicted that DO standard violations would occur 33 total days out of the year.

5. An evaluation of costs incurred indicates that 25 percent BOD control of wet-weather flow, while providing secondary treatment of dry-weather sanitary flow, is an effective treatment strategy. Violations are reduced to 26 days out of the year at an incremental cost of approximately $800,000/yr.

6. The benefits received from a reduction of shock loads from urban runoff are not readily quantifiable but should be considered when compared to strategies that involve high levels of municipal wastewater control.

SECTION II

RECOMMENDATIONS

DEMOGRAPHIC CHARACTERISTICS

There does not exist, at present, reliable information regarding land use in urban areas in the United States which is developed from a consistent set of assumptions and definitions. This information is vital to assessments such as this one which are based on control costs per acre of "urban" land. A comprehensive and meticulous data gathering effort is needed to provide the improved information base on land use.

Significant gaps exist in available information on population and area served by type of sewerage system. More refined estimates are needed for combined sewer systems. First estimates need to be made of storm sewered and unsewered areas. Also, the number of overflow points needs to be inventoried. This effort would need to include an unambiguous way to distinguish "drainage channels" from "receiving waters." Given some standardized definition of terms, much valuable information could be obtained from current USEPA 208 planning studies.

RUNOFF AND QUALITY PREDICTION

Both runoff and quality prediction techniques may be improved through use of additional data. Since a large amount of data presently exists, it needs to be aggregated to enable comparative analyses to be performed. In this manner, useful statistical and regression relationships can be developed incorporating several demographic and hydrologic parameters, and regional variations may be more easily discerned. Data collected as part of current USEPA 208 studies should be incorporated. In addition, studies are needed in which both surface (e.g., "dust and dirt") and effluent (e.g., concentration) data are gathered simultaneously so that their relationship may be determined.

Future reports containing data should be careful to define precisely the quality parameters being used along with the averaging method employed. Flow-weighted average concentrations are more meaningful than arithmetic averages. Since demographic data are obtainable through census publications, such data, especially population density and precise land use information, should be reported for each area on which sampling is being conducted.

COST ASSESSMENT METHODOLOGY

The general methodology appears to work well. It needs to be extended to cover a wider range of situations. More sensitivity analysis is needed.

The cost and performance data on storage and treatment units need to be refined.

The methodology should be extended to account for the interrelationship between storage and treatment especially at higher levels of control where detention times in storage are significant. Associated with this effort could be a study of the impact of different reservoir operating policies. A constant release rate is assumed at present.

The isoquant equations should be refined to account for snowmelt. An updated relationship between annual overflow events and percent runoff control should be included.

Further sensitivity analysis of the cost allocation formulation needs to be made to derive generalized curves for various combinations of influent treatment plant flow equalization and storage capacities.

The tradeoff with tertiary treatment should be evaluated using other pollutants such as nutrients as the effectiveness criterion.

IMPACT OF URBAN WATER POLLUTION CONTROL ON RECEIVING WATER QUALITY

In order to have basic information on the behavior of receiving waters when subjected to pollutant stresses beyond their natural assimilative capacity, continuous hydrologic models coupled with pollutant transport routines must be applied. It was found throughout this study that large amounts of data were available; however, these data were somewhat less than adequate for modeling purposes. In the area of data requirements some specific recommendations are:

1. The water quality indicators that will be used for planning purposes should be clearly identified before actual data collection.

2. The data collection system should be designed to be representative of the receiving water being investigated. Flow velocities, diffusion and dispersion coefficients, tidal cycles, etc., affect the frequency of sampling.

3. Sampling of receiving waters should be conducted before, during, and after periods of urban runoff.

4. The laboratory procedures utilized should be clearly described, for example, whether natural or artificial (deionized) dilution water was used in performing the standard BOD$_5$ test and the particle size and settling velocity definition of suspended solids.

5. Kinetic reactions of biochemical tests (i.e., deoxygenation rates of BOD) should be reported and compared with other locally obtained values.

6. Additional data on photosynthesis, algal respiration, and benthic demand of water bodies are needed.

7. Measurements of the nitrogenous oxygen demand of waste inputs and the receiving water are needed, as they are becoming more significant since greater numbers of secondary treatment plants are operational.

8. Both mass loadings and concentrations of pollutants should be estimated and reported.

In the realm of modeling efforts, further work is required:

1. The response of receiving waters to urban runoff and dry-weather flow inputs should be characterized when storage of waste streams is considered in combination with treatment.

2. Simplified techniques to approximate the complex mechanisms of pollutant transport in lakes, bays, and estuaries should be developed.

SECTION III

DESCRIPTION OF THE URBANIZED AREAS

This section presents a summary and analysis of data on the following characteristics of urban areas:

- population, land area and location; and
- population density and land use distribution.

These categories are discussed below.

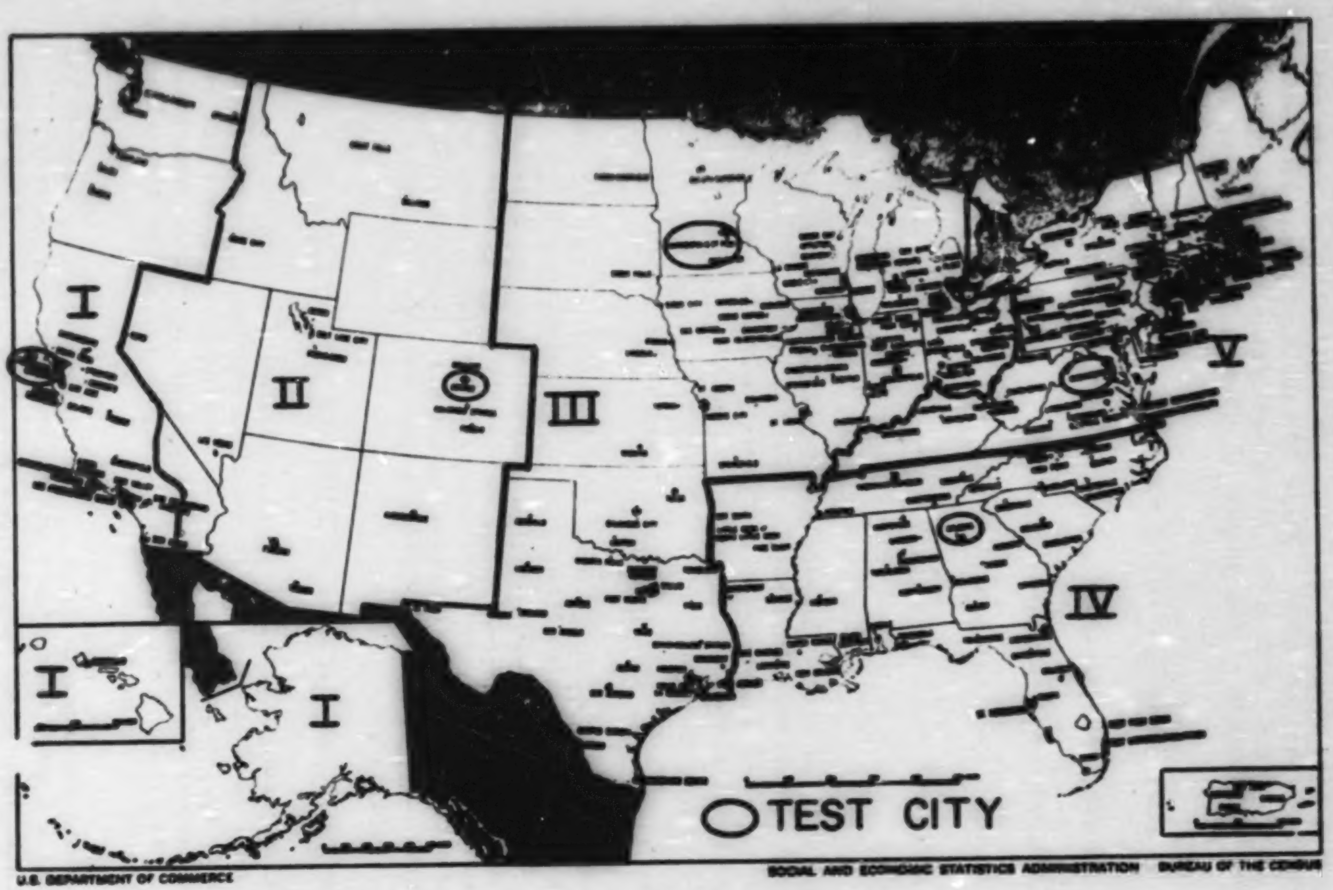
URBAN AREAS

Urban areas in this study have been taken as the 248 urbanized areas defined by the Bureau of the Census of the US Department of Commerce in the 1970 census and other urban areas. The 248 urbanized areas defined in 1970 are generally characterized as having:[1]

- a central city or urban core of 50,000 or more inhabitants;
- closely inhabited surroundings, consisting of incorporated places of 100 housing units or more; and small unincorporated parcels with population densities of 1,000 inhabitants per square mile or more (386 per square km); and
- other small unincorporated areas that may eliminate enclaves, square up the geometry of the urbanized area or provide a linkage to other enumeration districts fulfilling the overall criteria within 1 1/2 miles 2.4 km) of the main body of the urbanized area.

The distribution of urbanized areas across the United States is shown in Figure III-1, 1970 Urbanized Areas and Five Regions.

The choice of a sample of 50 urbanized areas was based upon a representative distribution reflecting variations in climate and geography. This sample of 20 percent of all urbanized areas was selected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TEST CITY
U.S. DEPARTMENT OF COMMERCE
SOCIAL AND ECONOMIC STATISTICS ADMINISTRATION
BUREAU OF THE CENSUS

Figure III-1. 1970 Urbanized Areas and Five Regions

Source: US Bureau of the Census, County and City Data Book, 1972 for further analysis. The 50 selected urbanized areas are listed in Table III-1, Demographic Characteristics of the Urban Areas, along with the remaining urbanized areas and the residual urban areas not located within urbanized areas. These 50 urbanized areas are denoted under column 7, "CODE" with a C. All other cities are coded "E". The population distribution of the sample of urbanized areas was as follows:

Population Range	Number of Urbanized Areas
$50{,}000 \le \text{Population} \le 100{,}000$	7
$100{,}000 < \text{Population} \le 250{,}000$	12
$250{,}000 < \text{Population} \le 500{,}000$	11
$500{,}000 < \text{Population} \le 1{,}000{,}000$	7
$1{,}000{,}000 < \text{Population}$	13

A sub-sample of the five cities selected for more intensive analysis (San Francisco, Denver, Minneapolis, Atlanta, and Washington, DC) is shown in Figure III-1 along with the five regions into which the country was partitioned.

POPULATION, LAND AREA, AND LOCATION

The 1970 census population and land area for each of the 248 urbanized areas were obtained from the County and City Data Book, 1972.[1] In addition, the total urban population for each state was obtained from the same source. If an urbanized area encompassed more than one state, its area and population were apportioned to the states based on the population of the major cities constituting the urbanized area. The results, presented by state and EPA region, are shown in Table III-1.

POPULATION DENSITY AND LAND USE DISTRIBUTION

The overall population density for an urbanized area may be obtained using the data in Table III-1. In general, population densities have decreased during the past generation reflecting the availability of improved transportation systems, the desire of individual home ownership, etc. No detailed data on urban land use for all of the urbanized areas in the US could be found.

For nine urbanized areas in Ontario, the area occupied by each of the following five types of land uses was determined: residential, institutional, industrial, commercial, and open space.[2] Land use maps, if available, were used. Aerial photographs were employed if land use

TABLE III-1 DEMOGRAPHIC CHARACTERISTICS OF THE URBAN AREAS

EPA RPG	STATE ID	URBANIZED AREA	1000 ACRES	1970 POP 1000	POP AVE PD	CODE
1	CT	BRIDGEPORT	95.	413.	4.33	E
1	CT	BRISTOL	24.	72.	3.04	E
1	CT	DANBURY	35.	67.	1.90	E
1	CT	HARTFORD	84.	465.	5.55	C
1	CT	MERIDEN	45.	98.	2.16	E
1	CT	NEW BRITAIN	25.	131.	5.25	E
1	CT	NEW HAVEN	68.	348.	5.08	E
1	CT	NORWALK	27.	107.	3.96	E
1	CT	STAMFORD	45.	185.	4.13	E
1	CT	WATERBURY	38.	157.	4.09	E
1	CT	OTHER URBAN AREAS	72.	301.	4.19	
1	CT	TOTAL FOR STATE	559.	2344.	4.19	
1	ME	LEWISTON	44.	65.	1.49	E
1	ME	PORTLAND	36.	106.	2.96	C
1	ME	OTHER URBAN AREAS	156.	336.	2.15	
1	ME	TOTAL FOR STATE	235.	507.	2.15	
1	MA	BOSTON	425.	2652.	6.24	C
1	MA	BROCKTON	34.	149.	4.39	E
1	MA	FALL RIVER	28.	139.	5.05	E
1	MA	FITCHBURG	39.	78.	2.00	E
1	MA	LAWRENCE	54.	200.	3.72	E
1	MA	LOWELL	40.	183.	4.61	E
1	MA	NEW BEDFORD	32.	134.	4.16	E
1	MA	PITTSFIELD	28.	63.	2.24	E
1	MA	SPRINGFIELD	152.	514.	3.37	F
1	MA	WORCESTER	54.	247.	4.59	E
1	MA	OTHER URBAN AREAS	91.	454.	4.98	
1	MA	TOTAL FOR STATE	966.	4813.	4.98	
1	NH	MANCHESTER	25.	95.	3.81	C
1	NH	NASHUA	22.	61.	2.80	E
1	NH	OTHER URBAN AREAS	78.	261.	3.34	
1	NH	TOTAL FOR STATE	125.	417.	3.34	
1	RI	PROVIDENCE	156.	795.	5.09	C
1	RI	OTHER URBAN AREAS	6.	31.	5.09	
1	RI	TOTAL FOR STATE	162.	826.	5.09	
1	VT	URBAN AREAS	35.	143.	4.14	E
1	VT	TOTAL FOR STATE	35.	143.	4.14	
1		TOTAL FOR REGION 1	2082.	9050.	4.35	
2	NJ	ATLANTIC CITY	43.	134.	3.13	F
2	NJ	NEW YORK CITY METRO	1309.	5688.	4.35	E
2	NJ	PHILADELPHIA METRO	31.	202.	6.48	E
2	NJ	TRENTON	42.	274.	6.59	E
2	NJ	VINELAND	54.	74.	1.36	E
2	NJ	TOTAL FOR STATE	1479.	6372.	4.31	
2	NY	ALBANY	97.	486.	5.03	C
2	NY	BINGHAMPTON	33.	167.	5.02	E
2	NY	BUFFALO	137.	1086.	7.93	E
2	NY	NEW YORK CITY	243.	10519.	43.25	E
2	NY	ROCHESTER	93.	601.	6.43	E
2	NY	SYRACUSE	61.	376.	6.12	E
2	NY	UTICA	48.	180.	3.75	E
2	NY	OTHER URBAN AREAS	117.	2196.	18.82	
2	NY	TOTAL FOR STATE	830.	15611.	18.82	
2		TOTAL FOR REGION 2	2309.	21983.	9.52	

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TABLE III-1 DEMOGRAPHIC CHARACTERISTICS OF THE URBAN AREAS

EPA REG	STATE ID	URBANIZED AREA	1000 ACRES	1970 POP 1000	POP AVE PD	CODE
3	DE	WILMINGTON	70.	371.	5.27	C
3	DE	OTHER URBAN AREAS	5.	24.	5.27	
3	DE	TOTAL FOR STATE	75.	395.	5.27	
3	DC	WASHINGTON,D.C.	39.	757.	19.26	C
3	DC	TOTAL FOR STATE	39.	757.	19.26	
3	MD	BALTIMORE	198.	1580.	7.96	E
3	MD	WASHINGTON DC METRO	77.	473.	6.16	E
3	MD	OTHER URBAN AREAS	128.	952.	7.46	
3	MD	TOTAL FOR STATE	403.	3005.	7.46	
3	PA	ALLENTOWN	63.	364.	5.74	E
3	PA	ALTOONA	13.	82.	6.41	E
3	PA	ERIE	28.	175.	6.21	E
3	PA	HARRISBURG	50.	241.	4.83	E
3	PA	JOHNSTOWN	18.	96.	5.36	E
3	PA	LANCASTER	25.	117.	4.69	E
3	PA	PHILADELPHIA	450.	3819.	8.49	E
3	PA	PITTSBURGH	381.	1846.	4.84	E
3	PA	READING	26.	168.	6.40	E
3	PA	SCRANTON	63.	204.	3.25	E
3	PA	WILKES-BARRE	53.	223.	4.20	E
3	PA	YORK	24.	123.	5.19	E
3	PA	OTHER URBAN AREAS	156.	975.	6.24	
3	PA	TOTAL FOR STATE	1350.	8433.	6.24	
3	VA	LYNCHBURG	24.	71.	3.00	E
3	VA	NEWPORT NEWS	92.	268.	2.93	E
3	VA	NORFOLK	191.	666.	3.49	E
3	VA	PETERSBURG	27.	101.	3.76	E
3	VA	RICHMOND	93.	416.	4.48	E
3	VA	ROANOKE	42.	157.	3.72	E
3	VA	WASHINGTON DC METRO	100.	1251.	12.45	E
3	VA	OTHER URBAN AREAS	0.	1.	5.15	
3	VA	TOTAL FOR STATE	569.	2933.	5.15	
3	WV	CHARLESTON	40.	158.	3.98	C
3	WV	HUNTINGTON	23.	121.	5.21	E
3	WV	STEUBENVILLE METRO	17.	40.	2.34	E
3	WV	WHEELING	18.	93.	5.19	E
3	WV	OTHER URBAN AREAS	64.	268.	4.21	
3	WV	TOTAL FOR STATE	162.	680.	4.21	
3		TOTAL FOR REGION 3	2598.	16203.	6.24	

TABLE III-1 DEMOGRAPHIC CHARACTERISTICS OF THE URBAN AREAS

EPA RFG	STATE ID	URBANIZED AREA	1000 ACRES	1970 POP 1000	POP AVE PD	CODE
4	AL	BIRMINGHAM	148.	558.	3.78	C
4	AL	GADSDEN	35.	68.	1.93	E
4	AL	HUNTSVILLE	76.	140.	1.85	E
4	AL	MOBILE	108.	258.	2.40	E
4	AL	MONTGOMERY	33.	139.	4.26	E
4	AL	TUSCALOOSA	28.	86.	3.05	E
4	AL	OTHER URBAN AREAS	257.	756.	2.94	
4	AL	TOTAL FOR STATE	683.	2011.	2.94	
4	FL	FT.LAUDERDALE	136.	616.	4.53	E
4	FL	GAINESVILLE	19.	69.	3.72	E
4	FL	JACKSONVILLE	225.	530.	2.36	C
4	FL	MIAMI	166.	1220.	7.36	C
4	FL	ORLANDO	88.	305.	3.41	E
4	FL	PENSACOLA	42.	167.	3.95	E
4	FL	ST.PETERSBURG	103.	495.	4.80	E
4	FL	TALLAHASSEE	19.	76.	4.06	E
4	FL	TAMPA	88.	369.	4.20	E
4	FL	WEST PALM BEACH	87.	288.	3.31	E
4	FL	OTHER URBAN AREAS	310.	1330.	4.29	
4	FL	TOTAL FOR STATE	1275.	5465.	4.29	
4	GA	ALBANY	21.	76.	3.60	E
4	GA	ATLANTA	278.	1173.	4.21	C
4	GA	AUGUSTA	37.	148.	4.01	E
4	GA	COLUMBUS	68.	209.	3.08	E
4	GA	MACON	33.	128.	3.92	E
4	GA	SAVANNAH	41.	166.	4.00	E
4	GA	OTHER URBAN AREAS	219.	869.	3.97	
4	GA	TOTAL FOR STATE	697.	2748.	3.97	
4	KY	HUNTINGTON METRO	13.	47.	3.73	E
4	KY	LEXINGTON	22.	140.	6.25	E
4	KY	LOUISVILLE	134.	739.	5.50	E
4	KY	OWENSBORO	8.	53.	6.60	E
4	KY	OTHER URBAN AREAS	124.	688.	5.54	
4	KY	TOTAL FOR STATE	304.	1687.	5.54	
4	MS	BILOXI	41.	121.	2.95	E
4	MS	JACKSON	46.	190.	4.13	C
4	MS	OTHER URBAN AREAS	189.	676.	3.57	
4	MS	TOTAL FOR STATE	276.	987.	3.57	
4	NC	ASHEVILLE	24.	72.	2.96	E
4	NC	CHARLOTTE	68.	280.	4.13	
4	NC	DURHAM	28.	101.	3.67	E
4	NC	FAYETTEVILLE	47.	161.	3.45	E
4	NC	GREENSBORO	39.	152.	3.89	E
4	NC	HIGHPOINT	33.	86.	2.62	E
4	NC	RALEIGH	45.	152.	3.35	E
4	NC	WILMINGTON	19.	58.	3.13	E
4	NC	WINSTON-SALEM	42.	146.	3.46	E
4	NC	OTHER URBAN AREAS	306.	1075.	3.51	
4	NC	TOTAL FOR STATE	651.	2287.	3.51	
4	SC	CHARLESTON	63.	228.	3.60	
4	SC	COLUMBIA	66.	242.	3.67	C
4	SC	GREENVILLE	45.	157.	3.46	E
4	SC	OTHER URBAN AREAS	169.	606.	3.59	
4	SC	TOTAL FOR STATE	344.	1233.	3.59	
4	TN	CHATTANOOGA	75.	224.	2.99	E
4	TN	KNOXVILLE	55.	190.	3.45	E
4	TN	MEMPHIS	155.	648.	4.20	C
4	TN	NASHVILLE	220.	448.	2.03	C
4	TN	OTHER URBAN AREAS	243.	781.	3.21	
4	TN	TOTAL FOR STATE	719.	2307.	3.21	
4		TOTAL FOR REGION 4	4949.	18745.	3.79	

TABLE III-1 DEMOGRAPHIC CHARACTERISTICS OF THE URBAN AREAS

EPA REG	STATE ID	URBANIZED AREA	1000 ACRES	1970 POP 1000	POP AVE PD	CODE
5	IL	AURORA	49.	233.	4.73	E
5	IL	BLOOMINGTON	13.	69.	5.36	E
5	IL	CHAMPAIGN	15.	100.	6.48	E
5	IL	CHICAGO	626.	5714.	9.13	E
5	IL	DAVENPORT METRO	23.	112.	4.97	E
5	IL	DECATUR	24.	100.	4.26	E
5	IL	JOLIET	35.	150.	4.25	E
5	IL	PEORIA	68.	247.	3.61	E
5	IL	ROCKFORD	39.	206.	5.28	E
5	IL	SPRINGFIELD	22.	121.	5.56	E
5	IL	OTHER URBAN AREAS	279.	2163.	7.75	
5	IL	TOTAL FOR STATE	1189.	9221.	7.75	
5	IN	ANDERSON	28.	81.	2.98	E
5	IN	CHICAGO METRO	191.	1000.	5.23	E
5	IN	EVANSVILLE	36.	186.	5.41	E
5	IN	FORT WAYNE	48.	225.	5.10	E
5	IN	INDIANAPOLIS	244.	820.	3.36	E
5	IN	LAFAYETTE	12.	79.	6.50	E
5	IN	MUNCIE	16.	90.	5.63	E
5	IN	SOUTH BEND	64.	280.	4.37	E
5	IN	TERRA HAUTE	20.	81.	3.96	E
5	IN	OTHER URBAN AREAS	130.	565.	4.33	
5	IN	TOTAL FOR STATE	779.	3371.	4.33	
5	MI	ANN ARBOR	29.	179.	6.22	E
5	MI	BAY CITY	17.	78.	4.69	E
5	MI	DETROIT	558.	3970.	7.11	E
5	MI	FLINT	61.	330.	5.37	E
5	MI	GRAND RAPIDS	93.	353.	3.78	E
5	MI	JACKSON	23.	78.	3.39	E
5	MI	KALAMAZOO	47.	152.	3.25	E
5	MI	LANSING	47.	230.	4.92	E
5	MI	MUSKEGON	33.	108.	3.19	E
5	MI	SAGINAW	28.	148.	5.26	E
5	MI	OTHER URBAN AREAS	156.	935.	6.01	
5	MI	TOTAL FOR STATE	1092.	6559.	6.01	
5	MN	DULUTH	46.	105.	2.31	E
5	MN	FARGO METRO	6.	31.	5.57	E
5	MN	MINNEAPOLIS	461.	1704.	3.69	E
5	MN	ROCHESTER	10.	57.	5.98	E
5	MN	OTHER URBAN AREAS	173.	630.	3.63	
5	MN	TOTAL FOR STATE	696.	2527.	3.63	
5	OH	AKRON	131.	543.	4.16	E
5	OH	CANTON	48.	284.	5.95	E
5	OH	CINCINNATI	218.	1110.	5.18	E
5	OH	CLEVELAND	413.	1960.	4.74	E
5	OH	COLUMBUS	150.	790.	5.25	E
5	OH	DAYTON	143.	686.	4.79	E
5	OH	HAMILTON	26.	91.	3.74	E
5	OH	LIMA	17.	70.	4.05	E
5	OH	LORAIN	68.	192.	2.83	E
5	OH	MANSFIELD	36.	78.	2.17	E
5	OH	SPRINGFIELD	16.	94.	5.96	E
5	OH	STEUBENVILLE	8.	45.	5.72	E
5	OH	TOLEDO	106.	488.	4.58	E
5	OH	YOUNGSTOWN	83.	395.	4.76	E
5	OH	OTHER URBAN AREAS	264.	1235.	4.68	
5	OH	TOTAL FOR STATE	1718.	8021.	4.68	
5	WI	APPLETON	24.	130.	5.42	E
5	WI	DULUTH METRO	26.	33.	1.24	E
5	WI	GREEN BAY	50.	129.	2.58	E
5	WI	KENOSHA	12.	84.	7.20	E
5	WI	LA CROSSE	15.	63.	4.10	E
5	WI	MADISON	44.	205.	4.66	E
5	WI	MILWAUKEE	292.	1252.	4.28	E
5	WI	OSHKOSH	8.	55.	6.61	E
5	WI	RACINE	18.	117.	6.53	E
5	WI	OTHER URBAN AREAS	199.	843.	4.23	
5	WI	TOTAL FOR STATE	688.	2911.	4.23	
5		TOTAL FOR REGION 5	6157.	37610.	5.30	

TABLE III-1 DEMOGRAPHIC CHARACTERISTICS OF THE URBAN AREAS

EPA REG	STATE ID	URBANIZED AREA	1000 ACRES	1970 POP 1000	POP AVE PD	CODE
6	AR	FORT SMITH	38.	76.	1.98	E
6	AR	LITTLE ROCK	61.	223.	3.67	C
6	AR	PINE BLUFF	13.	61.	4.54	E
6	AR	OTHER URBAN AREAS	168.	602.	3.70	
6	AR	TOTAL FOR STATE	301.	962.	3.70	
6	LA	BATON ROUGE	54.	249.	4.58	C
6	LA	LAFAYETTE	16.	78.	4.88	E
6	LA	LAKE CHARLES	22.	88.	4.04	E
6	LA	MONROE	26.	90.	3.52	C
6	LA	NEW ORLEANS	54.	962.	17.89	E
6	LA	SHREVEPORT	60.	234.	3.89	E
6	LA	OTHER URBAN AREAS	96.	705.	7.34	
6	LA	TOTAL FOR STATE	328.	2406.	7.34	
6	NM	ALBUQUERQUE	73.	297.	4.07	C
6	NM	OTHER URBAN AREAS	102.	414.	4.07	
6	NM	TOTAL FOR STATE	175.	711.	4.07	
6	OK	LAWTON	28.	96.	3.41	E
6	OK	OKLAHOMA CITY	217.	580.	2.67	E
6	OK	TULSA	115.	371.	3.22	C
6	OK	OTHER URBAN AREAS	238.	693.	2.91	
6	OK	TOTAL FOR STATE	598.	1740.	2.91	
6	TX	ABILENE	50.	90.	1.80	E
6	TX	AMARILLO	39.	127.	3.25	E
6	TX	AUSTIN	55.	264.	4.80	E
6	TX	BEAUMONT	48.	116.	2.42	E
6	TX	BROWNSVILLE	10.	53.	5.52	E
6	TX	BRYAN	21.	51.	2.41	E
6	TX	CORPUS CHRISTI	83.	213.	2.56	E
6	TX	DALLAS	431.	1338.	3.10	C
6	TX	EL PASO	76.	337.	4.42	C
6	TX	FORT WORTH	253.	677.	2.67	E
6	TX	GALVESTON	15.	62.	4.21	E
6	TX	HARLINGEN	22.	50.	2.30	E
6	TX	HOUSTON	345.	1678.	4.86	E
6	TX	LAREDO	14.	70.	4.97	E
6	TX	LUBBOCK	49.	150.	3.06	E
6	TX	MCALLEN	21.	91.	4.31	E
6	TX	MIDLAND	20.	60.	2.93	E
6	TX	ODESSA	16.	82.	5.13	E
6	TX	PORT ARTHUR	47.	116.	2.48	E
6	TX	SAN ANGELO	22.	66.	2.96	E
6	TX	SAN ANTONIO	143.	772.	5.41	E
6	TX	SHERMAN	22.	55.	2.46	E
6	TX	TEXARKANA	20.	58.	2.92	E
6	TX	TEXAS CITY	53.	84.	1.58	E
6	TX	TYLER	16.	60.	3.75	E
6	TX	WACO	58.	119.	2.07	E
6	TX	WICHITA FALL	27.	98.	3.65	E
6	TX	OTHER URBAN AREAS	570.	1999.	3.51	
6	TX	TOTAL FOR STATE	2546.	8934.	3.51	
6		TOTAL FOR REGION 6	3948.	14753.	3.74	

TABLE III-1 DEMOGRAPHIC CHARACTERISTICS OF THE URBAN AREAS

EPA REG	STATE ID	URBANIZED AREA	1000 ACRES	1970 POP 1000	POP AVE PD	CODE
7	IA	CEDAR RAPIDS	40.	132.	3.33	E
7	IA	DAVENPORT	53.	114.	2.15	E
7	IA	DES MOINES	70.	255.	3.64	E
7	IA	DUBUQUE	12.	65.	5.35	E
7	IA	SIOUX CITY	38.	96.	2.50	E
7	IA	WATERLOO	44.	113.	2.56	E
7	IA	OTHER URBAN AREAS	279.	840.	3.01	
7	IA	TOTAL FOR STATE	536.	1615.	3.01	
7	KS	KANSAS CITY METRO	55.	274.	4.98	E
7	KS	TOPEKA	38.	132.	3.49	C
7	KS	WICHITA	67.	302.	4.49	E
7	KS	OTHER URBAN AREAS	171.	777.	4.53	
7	KS	TOTAL FOR STATE	328.	1485.	4.53	
7	MO	COLUMBIA	27.	59.	2.19	E
7	MO	KANSAS CITY	260.	828.	3.18	E
7	MO	SPRINGFIELD	40.	121.	3.00	E
7	MO	ST.JOSEPH	20.	77.	3.78	E
7	MO	ST.LOUIS	295.	1883.	6.38	C
7	MO	OTHER URBAN AREAS	67.	310.	4.61	
7	MO	TOTAL FOR STATE	710.	3278.	4.61	
7	NE	LINCOLN	33.	153.	4.60	C
7	NE	OMAHA	97.	492.	5.09	E
7	NE	OTHER URBAN AREAS	54.	268.	4.96	
7	NE	TOTAL FOR STATE	184.	913.	4.96	
7		TOTAL FOR REGION 7	1758.	7291.	4.15	
8	CO	BOULDER	9.	69.	7.70	E
8	CO	COLORADO SPRINGS	58.	205.	3.56	E
8	CO	DENVER	188.	1047.	5.58	C
8	CO	PUEBLO	20.	103.	5.03	E
8	CO	OTHER URBAN AREAS	60.	313.	5.19	
8	CO	TOTAL FOR STATE	335.	1737.	5.19	
8	MT	BILLINGS	17.	71.	4.11	E
8	MT	GREAT FALLS	14.	71.	5.04	C
8	MT	OTHER URBAN AREAS	51.	230.	4.53	
8	MT	TOTAL FOR STATE	82.	372.	4.53	
8	ND	FARGO	10.	54.	5.51	C
8	ND	OTHER URBAN AREAS	40.	220.	5.51	
8	ND	TOTAL FOR STATE	50.	274.	5.51	
8	SD	SIOUX FALLS	17.	75.	4.34	C
8	SD	OTHER URBAN AREAS	51.	222.	4.34	
8	SD	TOTAL FOR STATE	68.	297.	4.34	
8	UT	OGDEN	39.	150.	3.84	E
8	UT	PROVO	42.	104.	2.50	E
8	UT	SALT LAKE CITY	118.	479.	4.07	C
8	UT	OTHER URBAN AREAS	33.	121.	3.69	
8	UT	TOTAL FOR STATE	231.	854.	3.69	
8	WY	URBAN AREAS	49.	201.	4.08	E
8	WY	TOTAL FOR STATE	49.	201.	4.08	
8		TOTAL FOR REGION 8	816.	3735.	4.58	

TABLE III-1 DEMOGRAPHIC CHARACTERISTICS OF THE URBAN AREAS

EPA REG	STATE ID	URBANIZED AREA	1000 ACRES	1970 POP 1000	POP AVE PD	CODE
9	AK	URBAN AREAS	49.	147.	2.99	E
9	AK	TOTAL FOR STATE	49.	147.	2.99	
9	AZ	PHOENIX	248.	863.	3.48	C
9	AZ	TUCSON	67.	294.	4.38	C
9	AZ	OTHER URBAN AREAS	68.	251.	3.67	
9	AZ	TOTAL FOR STATE	384.	1408.	3.67	
9	CA	BAKERSFIELD	36.	176.	4.82	E
9	CA	FRESNO	51.	263.	5.20	E
9	CA	LOS ANGELES	1006.	8351.	8.30	E
9	CA	MODESTO	22.	106.	4.87	E
9	CA	OXNARD	72.	285.	3.92	E
9	CA	SACRAMENTO	156.	634.	4.06	C
9	CA	SALINAS	10.	62.	6.46	E
9	CA	SAN BERNARDINO	198.	584.	2.94	E
9	CA	SAN DIEGO	244.	1198.	4.91	C
9	CA	SAN FRANCISCO	436.	2988.	6.86	C
9	CA	SAN JOSE	177.	1025.	5.78	E
9	CA	SANTA BARBARA	24.	130.	5.49	E
9	CA	SANTA ROSA	24.	75.	3.08	E
9	CA	SEASIDE	15.	93.	6.05	E
9	CA	SIMI VALLEY	16.	57.	3.56	E
9	CA	STOCKTON	30.	160.	5.32	E
9	CA	OTHER URBAN AREAS	311.	1995.	6.41	
9	CA	TOTAL FOR STATE	2828.	18142.	6.41	
9	HI	HONOLULU	74.	442.	6.01	E
9	HI	OTHER URBAN AREAS	33.	196.	6.01	
9	HI	TOTAL FOR STATE	106.	638.	6.01	
9	NV	LAS VEGAS	77.	237.	3.06	E
9	NV	RENO	24.	100.	4.11	C
9	NV	OTHER URBAN AREAS	18.	59.	3.31	
9	NV	TOTAL FOR STATE	120.	396.	3.31	
9		TOTAL FOR REGION 9	3487.	20731.	5.95	
10	ID	BOISE	19.	85.	4.58	C
10	ID	OTHER URBAN AREAS	66.	302.	4.58	
10	ID	TOTAL FOR STATE	85.	387.	4.58	
10	OR	EUGENE	35.	139.	3.95	E
10	OR	PORTLAND	171.	825.	4.83	C
10	OR	SALEM	24.	93.	3.93	E
10	OR	OTHER URBAN AREAS	75.	346.	4.60	
10	OR	TOTAL FOR STATE	305.	1403.	4.60	
10	WA	SEATTLE	264.	1238.	4.68	C
10	WA	SPOKANE	50.	230.	4.61	E
10	WA	TACOMA	83.	332.	4.02	E
10	WA	OTHER URBAN AREAS	149.	675.	4.54	
10	WA	TOTAL FOR STATE	546.	2475.	4.54	
10		TOTAL FOR REGION 10	935.	4265.	4.56	
		TOTAL FOR THE U.S.	29037.	149366.	5.14	

maps were unavailable. These photos presented a problem, in that they were taken at altitudes (1.6 miles or 2.6 km, approximately) that made differentiating among land uses difficult. The percentage of the land use in each of these five categories is shown in Table III-2, Land Use Distributions in Nine Ontario Cities. Note that, with the exception of West Toronto which has a very high average population density (40.1 persons per acre or 99 persons per ha), a large percent of the "urbanized" area falls in the open space category. This large amount of open space results from the definition of urbanized areas which includes population densities as low as one person per acre (2.5 persons per ha). Thus, this definition includes significant acreages of land which are undeveloped and would not be served by sewerage systems.

Manvel et al. present data on land use in 106 US cities.[3] Analysis of these data indicates that the proportion of the urbanized area in each land use category was relatively similar after deducting for the proportion of the urbanized area which is in the "undeveloped" category. This category is deducted from the total urbanized area to obtain the developed portion of the urbanized area. Figure III-2, Percent Undeveloped Land Use (US) and Open Space Land Use (Ontario) vs Population Density, shows the percent undeveloped land as a function of population density for the US cities and the percent open land for the Ontario cities. The "open" category would include undeveloped land and developed open space land, e.g., parks. As can be seen from Figure III-2, the Ontario cities generally fall above the line of best fit for the US undeveloped land. This result appears reasonable since the "open space" category would include the "undeveloped" land. Thus, it seemed reasonable to use the US equation to estimate the percent of the urbanized area which is undeveloped, i.e.,

$$Z = 1.0\ e^{-0.170(PD)} \qquad (r = -0.57) \qquad \text{(III-1)}$$

where Z = proportion undeveloped land,

PD = average gross (developed and undeveloped) population density, persons per acre, and

r = correlation coefficient ($-1.0 \leq r \leq 1.0$).

Using this relationship, then the developed population density, PD_d, can be expressed as a function of the gross population density using

$$PD_d = \frac{PD}{(1-Z)} = \frac{PD\ e^{0.17PD}}{e^{0.17PD}-1}. \qquad \text{(III-2)}$$

TABLE III-2. LAND USE DISTRIBUTIONS IN NINE ONTARIO CITIES[a]

Urbanized Area	Population Density persons/acre (persons/ha)	% of Urbanized Area in Indicated Land Use					
		Residential	Commercial	Industrial	Institutional	Open	Total
Burlington	5.84 (14.42)	34.0	3.0	3.0	5.0	55.0	100
Guelph	5.01 (12.37)	29.0	3.0	8.0	6.0	54.0	100
Kingston	10.39 (25.66)	32.0	5.0	7.0	12.0	44.0	100
Kitchener-Waterloo	6.70 (16.55)	27.0	4.0	10.0	2.0	57.0	100
St. Catharines	6.56 (16.20)	41.0	4.0	6.0	6.0	43.0	100
Sault Ste. Marie	5.56 (13.73)	40.0	4.0	19.0	4.0	33.0	100
Thunder Bay	6.89 (17.02)	34.0	13.0	12.0	6.0	35.0	100
Toronto, West	40.10 (99.05)	58.0	19.0	14.0	4.0	5.0	100
Windsor	7.63 (18.85)	38.0	6.0	10.0	3.0	43.0	100
Average	10.52 (25.98)	37.0	6.8	9.9	5.3	41.0	100

[a] American Public Works Association and University of Florida, "Evaluation of the Magnitude and Significance of Pollution Loading from Urban Stormwater Runoff - Ontario," Environmental Protection Service and Ontario Ministry of Environment, Toronto, 1976.

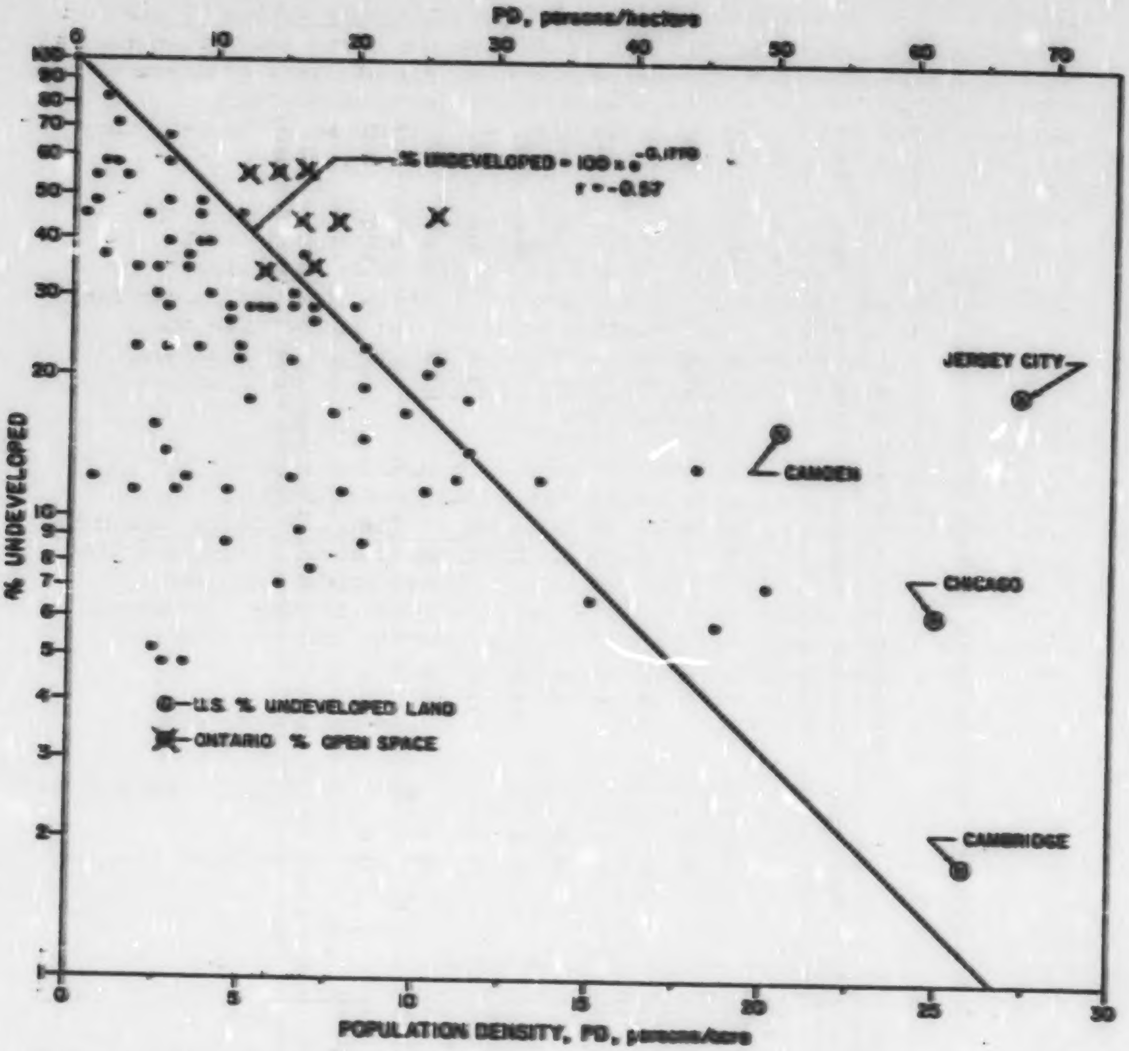

Figure III-2. Percent Undeveloped Land Use (US) and Open Space Land Use (Ontario) vs Population Density. Note that best fit line is forced through point 100 percent at PD = 0.

Equation III-2 is shown in Figure III-3, Relationship Between Gross and Developed Population Density. Note that the developed population density is about six persons per acre at the lowest level of urbanization (one person per acre). The developed population density approaches the gross population density as PD increases. Indeed, they are quite close at PD $\geq$ 25 persons per acre (62 persons per ha).

After correcting for the percent undeveloped, the proportion of the land in the developed uses was determined as a percent of developed urban land only. After this transformation was made, the percent of land in the developed uses was statistically independent of population density. The resultant distribution of developed land by use and undeveloped land is shown in Table III-3, Distribution of Developed Land Uses in Ontario Test Cities and US Cities. Note the similarity of the Ontario and US land use distributions.

The land distributions for all US cities are determined using equation III-1 and the US land use distributions shown in Table III-3. The results are presented in Table III-4, Land Use Distribution for the Urban Areas in the United States. In determining the control costs, only the developed portion of the urbanized area is considered. Thus, it is important to check the validity of this assumption in future assessments. Actual field data need to be gathered and analyzed using a consistent set of assumptions regarding land use categories.

Table III-3. DISTRIBUTION OF DEVELOPED LAND USES IN ONTARIO TEST CITIES AND US CITIES

	% of Total	
Land Use	Ontario[b]	US
Residential	52.5	58.4
Commercial	9.0	8.6
Industrial	14.1	14.8
Other[a]	24.4	18.2

[a] Recreational, schools and colleges, and cemeteries.

[b] American Public Works Association and University of Florida, "Evaluation of the Magnitude and Significance of Pollution Loading from Urban Stormwater Runoff - Ontario," Environmental Protection Service and Ontario Ministry of Environment, Toronto, 1976.

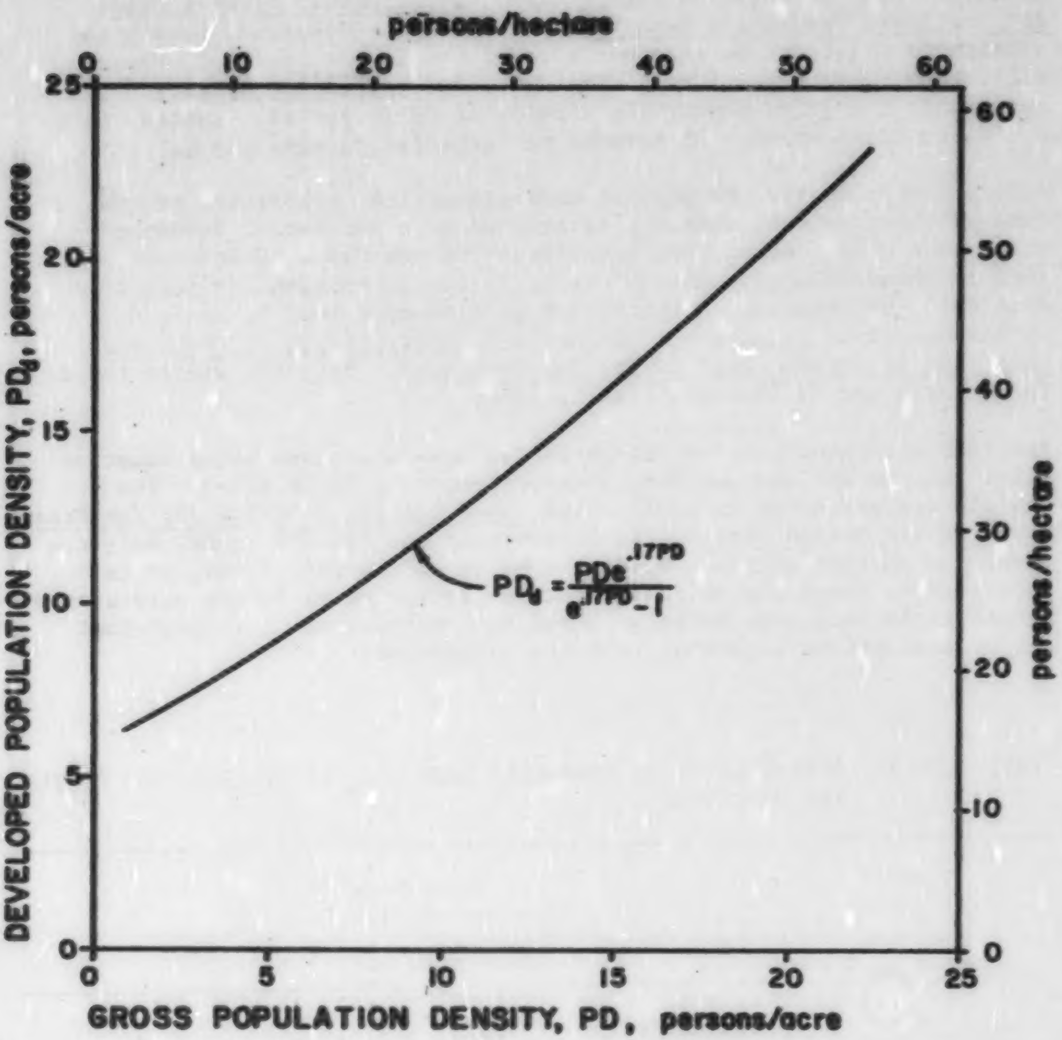

Figure III-3. Relationship Between Gross and Developed Population Density

TABLE III-4 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA RGE	STATE ID	URBANIZED AREA	LAND USE AS % OF TOTAL AREA					
			UNDV	RES	COMM	INDL	OTH	TOTAL
1	CT	BRIDGEPORT	47.9	30.4	4.5	7.7	9.5	100.0
1	CT	BRISTOL	59.6	23.6	3.5	6.0	7.3	100.0
1	CT	DANBURY	72.4	16.1	2.4	4.1	5.0	100.0
1	CT	HARTFORD	39.0	35.7	5.3	9.0	11.1	100.0
1	CT	MERIDEN	69.3	17.9	2.6	4.5	5.6	100.0
1	CT	NEW BRITAIN	41.0	34.5	5.1	8.7	10.7	100.0
1	CT	NEW HAVEN	42.1	33.8	5.0	8.6	10.5	100.0
1	CT	NORWALK	50.8	28.7	4.2	7.3	8.9	100.0
1	CT	STAMFORD	49.6	29.5	4.3	7.5	9.2	100.0
1	CT	WATERBURY	49.9	29.3	4.3	7.4	9.1	100.0
1	CT	OTHER URBAN AREAS	50.0	29.2	4.3	7.4	9.1	100.0
1	CT	AVE. FOR STATE	50.0	29.2	4.3	7.4	9.1	100.0
1	ME	LEWISTON	77.6	13.1	1.9	3.3	4.1	100.0
1	ME	PORTLAND	60.5	23.1	3.4	5.8	7.2	100.0
1	ME	OTHER URBAN AREAS	69.9	17.6	2.6	4.5	5.5	100.0
1	ME	AVE. FOR STATE	69.9	17.6	2.6	4.5	5.5	100.0
1	MA	BOSTON	34.6	38.2	5.6	9.7	11.9	100.0
1	MA	BROCKTON	47.4	30.7	4.5	7.8	9.6	100.0
1	MA	FALL RIVER	42.4	33.7	5.0	8.5	10.5	100.0
1	MA	FITCHBURG	71.2	16.8	2.5	4.3	5.2	100.0
1	MA	LAWRENCE	53.1	27.4	4.0	6.9	8.5	100.0
1	MA	LOWELL	45.7	31.7	4.7	8.0	9.9	100.0
1	MA	NEW BEDFORD	35.1	37.9	5.6	9.6	11.8	100.0
1	MA	PITTSFIELD	68.4	18.5	2.7	4.7	5.8	100.0
1	MA	SPRINGFIELD	56.3	25.5	3.8	6.5	7.9	100.0
1	MA	WORCESTER	45.8	31.7	4.7	8.0	9.9	100.0
1	MA	OTHER URBAN AREAS	44.2	32.6	4.8	8.3	10.2	100.0
1	MA	AVE. FOR STATE	44.2	32.6	4.8	8.3	10.2	100.0
1	NH	MANCHESTER	52.4	27.8	4.1	7.1	8.7	100.0
1	NH	NASHUA	62.1	22.1	3.3	5.6	6.9	100.0
1	NH	OTHER URBAN AREAS	56.9	25.2	3.7	6.4	7.8	100.0
1	NH	AVE. FOR STATE	56.9	25.2	3.7	6.4	7.8	100.0
1	RI	PROVIDENCE	42.1	33.8	5.0	8.6	10.5	100.0
1	RI	OTHER URBAN AREAS	42.1	33.8	5.0	8.6	10.5	100.0
1	RI	AVE. FOR STATE	42.1	33.8	5.0	8.6	10.5	100.0
1	VT	URBAN AREAS	49.5	29.5	4.3	7.5	9.2	100.0
1	VT	AVE. FOR STATE	49.5	29.5	4.3	7.5	9.2	100.0
1		AVE. FOR REGION 1	49.3	29.6	4.4	7.5	9.2	100.0
2	NJ	ATLANTIC CITY	58.8	24.1	3.5	6.1	7.5	100.0
2	NJ	NEW YORK CITY METRO	47.8	30.5	4.5	7.7	9.5	100.0
2	NJ	PHILADELPHIA METRO	33.5	38.9	5.7	9.8	12.1	100.0
2	NJ	TRENTON	32.6	39.3	5.8	10.0	12.3	100.0
2	NJ	VINELAND	79.4	12.1	1.8	2.9	3.8	100.0
2	NJ	AVE. FOR STATE	48.5	30.1	4.4	7.6	9.4	100.0
2	NY	ALBANY	42.5	33.6	4.9	8.5	10.5	100.0
2	NY	BINGHAMPTON	42.6	33.5	4.9	8.5	10.4	100.0
2	NY	BUFFALO	26.0	43.2	6.4	11.0	13.5	100.0
2	NY	NEW YORK CITY	0.1	58.4	8.6	14.8	18.2	100.0
2	NY	ROCHESTER	33.5	38.8	5.7	9.8	12.1	100.0
2	NY	SYRACUSE	35.3	37.8	5.6	9.6	11.8	100.0
2	NY	UTICA	52.9	27.5	4.1	7.0	8.6	100.0
2	NY	OTHER URBAN AREAS	23.8	44.5	6.6	11.3	13.9	100.0
2	NY	AVE. FOR STATE	23.8	44.5	6.6	11.3	13.9	100.0
2		AVE. FOR REGION 2	39.6	35.3	5.2	8.9	11.0	100.0

TABLE III-4 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA REG	STATE ID	URBANIZED AREA	LAND USE AS % OF TOTAL AREA UNDV	RES	COMM	INDL	OTH	TOTAL
3	DE	WILMINGTON	40.8	34.6	5.1	8.8	10.8	100.0
3	DE	OTHER URBAN AREAS	40.8	34.6	5.1	8.8	10.8	100.0
3	DE	AVE. FOR STATE	40.8	34.6	5.1	8.8	10.8	100.0
3	DC	WASHINGTON,D.C.	3.8	56.2	8.3	14.2	17.5	100.0
3	DC	AVE. FOR STATE	3.8	56.2	8.3	14.2	17.5	100.0
3	MD	BALTIMORE	25.8	43.3	6.4	11.0	13.5	100.0
3	MD	WASHINGTON DC METRO	35.1	37.9	5.6	9.6	11.8	100.0
3	MD	OTHER URBAN AREAS	28.4	41.8	6.2	10.6	13.0	100.0
3	MD	AVE. FOR STATE	28.4	41.8	6.2	10.6	13.0	100.0
3	PA	ALLENTOWN	37.7	36.4	5.4	9.2	11.3	100.0
3	PA	ALTOONA	33.7	38.7	5.7	9.8	12.1	100.0
3	PA	ERIE	34.8	38.1	5.6	9.7	11.9	100.0
3	PA	HARRISBURG	44.0	32.7	4.8	8.3	10.2	100.0
3	PA	JOHNSTOWN	40.2	34.9	5.1	8.8	10.9	100.0
3	PA	LANCASTER	45.1	32.1	4.7	8.1	10.0	100.0
3	PA	PHILADELPHIA	23.6	44.6	6.6	11.3	13.9	100.0
3	PA	PITTSBURGH	43.9	32.7	4.8	8.3	10.2	100.0
3	PA	READING	33.7	38.7	5.7	9.8	12.1	100.0
3	PA	SCRANTON	57.5	28.8	3.7	6.3	7.7	100.0
3	PA	WILKES-BARRE	49.0	29.8	4.4	7.6	9.3	100.0
3	PA	YORK	41.4	34.2	5.0	8.7	10.7	100.0
3	PA	OTHER URBAN AREAS	36.3	37.2	5.5	9.4	11.6	100.0
3	PA	AVE. FOR STATE	36.3	37.2	5.5	9.4	11.6	100.0
3	VA	LYNCHBURG	56.1	25.6	3.8	6.5	8.0	100.0
3	VA	NEWPORT NEWS	60.8	22.9	3.4	5.8	7.1	100.0
3	VA	NORFOLK	55.2	26.1	3.8	6.6	8.1	100.0
3	VA	PETERSBURG	52.8	27.6	4.1	7.0	8.6	100.0
3	VA	RICHMOND	46.7	31.1	4.6	7.9	9.7	100.0
3	VA	ROANOKE	53.2	27.4	4.0	6.9	8.5	100.0
3	VA	WASHINGTON DC METRO	12.0	51.4	7.6	13.0	16.0	100.0
3	VA	OTHER URBAN AREAS	46.9	31.0	4.6	7.9	9.7	100.0
3	VA	AVE. FOR STATE	46.9	31.0	4.6	7.9	9.7	100.0
3	WV	CHARLESTON	50.8	28.7	4.2	7.3	9.0	100.0
3	WV	HUNTINGTON	36.3	37.2	5.5	9.4	11.6	100.0
3	WV	STEUBENVILLE METRO	61.4	22.6	3.3	5.7	7.0	100.0
3	WV	WHEELING	41.4	34.2	5.0	8.7	10.7	100.0
3	WV	OTHER URBAN AREAS	47.5	30.7	4.5	7.8	9.6	100.0
3	WV	AVE. FOR STATE	47.5	30.7	4.5	7.8	9.6	100.0
3		AVE. FOR REGION 3	37.7	36.4	5.4	9.2	11.3	100.0

TABLE III-4 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA REG	STATE ID	URBANIZED AREA	LAND USE AS % OF TOTAL AREA UNDV	RES	COMM	INDL	OTH	TOTAL
4	AL	BIRMINGHAM	51.7	28.2	4.1	7.1	8.8	100.0
4	AL	GADSDEN	72.0	14.3	2.4	6.1	5.1	100.0
4	AL	HUNTSVILLE	73.0	15.8	2.3	4.0	4.9	100.0
4	AL	MOBILE	68.5	19.6	2.9	5.0	6.1	100.0
4	AL	MONTGOMERY	48.5	30.1	4.8	7.6	9.4	100.0
4	AL	TUSCALOOSA	59.5	23.7	3.5	6.0	7.4	100.0
4	AL	OTHER URBAN AREAS	61.3	22.6	3.3	5.7	7.0	100.0
4	AL	AVE. FOR STATE	61.3	22.6	3.3	5.7	7.0	100.0
4	FL	FT. LAUDERDALE	46.3	31.3	4.6	7.9	9.8	100.0
4	FL	GAINESVILLE	53.3	27.4	4.0	6.9	8.5	100.0
4	FL	JACKSONVILLE	67.0	19.3	2.8	4.9	6.0	100.0
4	FL	MIAMI	28.6	41.7	6.1	10.6	13.0	100.0
4	FL	ORLANDO	50.1	26.8	3.4	6.8	8.3	100.0
4	FL	PENSACOLA	51.1	28.6	4.2	7.2	8.9	100.0
4	FL	ST. PETERSBURG	44.5	32.6	4.8	8.3	10.2	100.0
4	FL	TALLAHASSEE	50.1	29.1	4.3	7.6	9.1	100.0
4	FL	TAMPA	47.3	30.8	4.5	7.8	9.6	100.0
4	FL	WEST PALM BEACH	57.0	25.1	3.7	6.6	7.6	100.0
4	FL	OTHER URBAN AREAS	50.0	29.2	4.3	7.4	9.1	100.0
4	FL	AVE. FOR STATE	50.0	29.2	4.3	7.4	9.1	100.0
4	GA	ALBANY	43.2	33.2	4.9	8.4	10.3	100.0
4	GA	ATLANTA	48.8	29.9	4.4	7.6	9.3	100.0
4	GA	AUGUSTA	50.5	28.9	4.3	7.3	9.0	100.0
4	GA	COLUMBUS	59.3	23.8	3.5	6.0	7.4	100.0
4	GA	MACON	51.3	28.4	4.2	7.2	8.9	100.0
4	GA	SAVANNAH	50.6	28.8	4.3	7.3	9.0	100.0
4	GA	OTHER URBAN AREAS	50.5	28.9	4.3	7.3	9.0	100.0
4	GA	AVE. FOR STATE	50.5	28.9	4.3	7.3	9.0	100.0
4	KY	HUNTINGTON METRO	53.1	27.0	4.0	6.9	8.5	100.0
4	KY	LEXINGTON	34.6	38.2	5.6	9.7	11.9	100.0
4	KY	LOUISVILLE	39.3	35.5	5.2	9.0	11.1	100.0
4	KY	OWENSBORO	30.9	40.3	5.9	10.2	12.6	100.0
4	KY	OTHER URBAN AREAS	39.2	35.5	5.2	9.0	11.1	100.0
4	KY	AVE. FOR STATE	39.2	35.5	5.2	9.0	11.1	100.0
4	MS	BILOXI	60.5	23.1	3.4	5.8	7.2	100.0
4	MS	JACKSON	49.6	29.4	4.3	7.5	9.2	100.0
4	MS	OTHER URBAN AREAS	54.7	26.4	3.9	6.7	8.2	100.0
4	MS	AVE. FOR STATE	54.7	26.4	3.9	6.7	8.2	100.0
4	NC	ASHEVILLE	60.5	23.1	3.4	5.9	7.2	100.0
4	NC	CHARLOTTE	49.6	29.4	4.3	7.5	9.2	100.0
4	NC	DURHAM	53.6	27.1	4.0	6.9	8.4	100.0
4	NC	FAYETTEVILLE	55.7	25.8	3.8	6.6	8.1	100.0
4	NC	GREENSBORO	51.6	28.3	4.2	7.2	8.8	100.0
4	NC	HIGHPOINT	61.9	22.3	3.3	5.6	6.9	100.0
4	NC	RALEIGH	56.8	25.3	3.7	6.4	7.8	100.0
4	NC	WILMINGTON	58.8	24.1	3.5	6.1	7.5	100.0
4	NC	WINSTON-SALEM	56.5	25.4	3.7	6.4	7.9	100.0
4	NC	OTHER URBAN AREAS	55.2	26.2	3.9	6.6	8.2	100.0
4	NC	AVE. FOR STATE	55.2	26.2	3.9	6.6	8.2	100.0
4	SC	CHARLESTON	54.3	26.7	3.9	6.8	8.3	100.0
4	SC	COLUMBIA	53.6	27.1	4.0	6.9	8.4	100.0
4	SC	GREENVILLE	55.6	25.9	3.8	6.6	8.1	100.0
4	SC	OTHER URBAN AREAS	54.3	26.7	3.9	6.8	8.3	100.0
4	SC	AVE. FOR STATE	54.3	26.7	3.9	6.8	8.3	100.0
4	TN	CHATTANOOGA	60.1	23.3	3.4	5.9	7.3	100.0
4	TN	KNOXVILLE	55.6	25.9	3.8	6.6	8.1	100.0
4	TN	MEMPHIS	40.7	34.7	5.1	8.8	10.8	100.0
4	TN	NASHVILLE	70.8	17.1	2.5	4.3	5.3	100.0
4	TN	OTHER URBAN AREAS	59.4	23.7	3.5	6.0	7.4	100.0
4	TN	AVE. FOR STATE	59.4	23.7	3.5	6.0	7.4	100.0
4		AVE. FOR REGION 4	53.6	27.1	4.0	6.9	8.4	100.0

TABLE III-4 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA REG	STATE ID	URBANIZED AREA	LAND USE AS % OF TOTAL AREA					
			UNDV	RES	COMM	INDL	OTH	TOTAL
5	IL	AURORA	44.8	32.3	4.6	8.2	10.1	100.0
5	IL	BLOOMINGTON	40.0	35.0	5.2	8.9	[illegible]	100.0
5	IL	CHAMPAIGN	[illegible]	[illegible]	[illegible]	11.4	[illegible]	100.0
5	IL	CHICAGO	21.3	[illegible]	[illegible]	11.7	[illegible]	100.0
5	IL	DAVENPORT METRO	[illegible]	33.3	[illegible]	[illegible]	[illegible]	100.0
5	IL	DECATUR	[illegible]	[illegible]	4.4	7.6	[illegible]	100.0
5	IL	JOLIET	[illegible]	30.9	4.6	7.8	[illegible]	100.0
5	IL	PEORIA	54.3	26.8	3.9	6.8	[illegible]	100.0
5	IL	ROCKFORD	40.6	34.9	5.1	[illegible]	[illegible]	100.0
5	IL	SPRINGFIELD	[illegible]	35.7	5.3	[illegible]	[illegible]	100.0
5	IL	OTHER URBAN AREAS	28.7	41.6	6.1	10.5	13.0	100.0
5	IL	AVE. FOR STATE	28.7	41.6	6.1	10.5	13.0	100.0
5	IN	ANDERSON	27.3	42.6	[illegible]	10.8	13.2	100.0
5	IN	CHICAGO METRO	[illegible]	34.6	[illegible]	8.7	[illegible]	100.0
5	IN	EVANSVILLE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	IN	FORT WAYNE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	IN	INDIANAPOLIS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	IN	LAFAYETTE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	IN	MUNCIE	[illegible]	34.0	[illegible]	9.1	[illegible]	100.0
5	IN	SOUTH BEND	47.6	30.6	[illegible]	7.8	[illegible]	100.0
5	IN	TERRA HAUTE	51.1	28.6	4.2	7.2	[illegible]	100.0
5	IN	OTHER URBAN AREAS	47.1	30.9	4.6	7.8	9.6	100.0
5	IN	AVE. FOR STATE	47.1	30.9	4.6	7.8	9.6	100.0
5	MI	ANN ARBOR	34.8	38.1	[illegible]	9.7	[illegible]	100.0
5	MI	BAY CITY	[illegible]	32.1	[illegible]	8.1	[illegible]	100.0
5	MI	DETROIT	[illegible]	41.0	[illegible]	10.4	[illegible]	100.0
5	MI	FLINT	40.1	[illegible]	[illegible]	8.9	[illegible]	100.0
5	MI	GRAND RAPIDS	[illegible]	27.7	[illegible]	7.0	[illegible]	100.0
5	MI	JACKSON	[illegible]	[illegible]	[illegible]	6.5	[illegible]	100.0
5	MI	KALAMAZOO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	MI	LANSING	43.3	33.1	4.9	8.4	10.3	100.0
5	MI	MUSKEGON	[illegible]	24.4	[illegible]	[illegible]	[illegible]	100.0
5	MI	SAGINAW	[illegible]	[illegible]	5.1	8.7	10.8	100.0
5	MI	OTHER URBAN AREAS	37.3	36.6	5.4	9.3	11.4	100.0
5	MI	AVE. FOR STATE	37.3	36.6	5.4	9.3	11.4	100.0
5	MN	DULUTH	67.6	18.9	2.8	4.8	5.9	100.0
5	MN	FARGO METRO	[illegible]	35.7	5.1	9.1	[illegible]	100.0
5	MN	MINNEAPOLIS	[illegible]	27.2	[illegible]	[illegible]	[illegible]	100.0
5	MN	ROCHESTER	36.4	37.1	[illegible]	[illegible]	[illegible]	100.0
5	MN	OTHER URBAN AREAS	54.1	26.8	3.9	6.8	8.3	100.0
5	MN	AVE. FOR STATE	54.1	26.8	3.9	6.8	8.3	100.0
5	OH	AKRON	49.3	29.6	4.4	7.5	9.2	100.0
5	OH	CANTON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	OH	CINCINNATI	[illegible]	[illegible]	[illegible]	8.7	10.7	100.0
5	OH	CLEVELAND	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	OH	COLUMBUS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	OH	DAYTON	44.3	32.5	[illegible]	8.2	[illegible]	100.0
5	OH	HAMILTON	[illegible]	27.5	[illegible]	[illegible]	[illegible]	100.0
5	OH	LIMA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	OH	LORAIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	OH	MANSFIELD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	OH	SPRINGFIELD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	OH	STEUBENVILLE	[illegible]	36.3	[illegible]	9.2	[illegible]	100.0
5	OH	TOLEDO	[illegible]	31.7	[illegible]	[illegible]	[illegible]	100.0
5	OH	YOUNGSTOWN	[illegible]	32.5	[illegible]	[illegible]	10.1	100.0
5	OH	OTHER URBAN AREAS	45.3	32.0	4.7	8.1	10.0	100.0
5	OH	AVE. FOR STATE	45.3	32.0	4.7	8.1	10.0	100.0
5	WI	APPLETON	39.3	[illegible]	5.2	[illegible]	[illegible]	100.0
5	WI	DULUTH METRO	80.3	11.5	[illegible]	[illegible]	[illegible]	100.0
5	WI	GREEN BAY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	WI	KENOSHA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	WI	LA CROSSE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	WI	MADISON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	WI	MILWAUKEE	[illegible]	30.2	[illegible]	7.7	[illegible]	100.0
5	WI	OSHKOSH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	WI	RACINE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
5	WI	OTHER URBAN AREAS	49.7	29.4	4.3	7.4	9.2	100.0
5	WI	AVE. FOR STATE	49.7	29.4	4.3	7.4	9.2	100.0
5		AVE. FOR REGION 5	42.4	33.6	5.0	8.5	10.5	100.0

TABLE III-4 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA RFG	STATE ID	URBANIZED AREA	LAND USE AS % OF TOTAL AREA UNDV	RES	COMM	INDL	OTH	TOTAL
6	AR	FORT SMITH	71.4	16.7	2.5	4.2	5.2	100.0
6	AR	LITTLE ROCK	52.6	27.1	5.0	6.9	8.4	100.0
6	AR	PINE BLUFF	46.5	31.0	4.8	8.0	9.8	100.0
6	AR	OTHER URBAN AREAS	58.8	26.1	3.5	4.1	7.5	100.0
6	AR	AVE. FOR STATE	58.8	26.1	3.5	4.1	7.5	100.0
6	LA	BATON ROUGE	45.9	31.6	4.7	8.0	9.8	100.0
6	LA	LAFAYETTE	43.7	32.9	4.8	8.3	10.3	100.0
6	LA	LAKE CHARLES	50.3	29.0	4.3	7.4	9.0	100.0
6	LA	MONROE	55.0	26.3	3.9	6.7	8.2	100.0
6	LA	NEW ORLEANS	4.6	55.6	8.2	14.1	17.5	100.0
6	LA	SHREVEPORT	51.4	28.3	4.5	7.2	8.6	100.0
6	LA	OTHER URBAN AREAS	39.1	35.6	5.2	9.0	11.1	100.0
6	LA	AVE. FOR STATE	39.1	35.6	5.2	9.0	11.1	100.0
6	NM	ALBUQUERQUE	50.1	29.2	4.3	7.4	9.1	100.0
6	NM	OTHER URBAN AREAS	50.1	29.2	4.3	7.4	9.1	100.0
6	NM	AVE. FOR STATE	50.1	29.2	4.3	7.4	9.1	100.0
6	OK	LAWTON	56.0	25.7	3.8	6.5	8.0	100.0
6	OK	OKLAHOMA CITY	63.5	21.3	3.1	5.4	6.6	100.0
6	OK	TULSA	57.8	26.4	3.6	6.2	7.7	100.0
6	OK	OTHER URBAN AREAS	61.1	22.7	3.3	5.8	7.1	100.0
6	OK	AVE. FOR STATE	61.1	22.7	3.3	5.8	7.1	100.0
6	TX	ABILENE	73.6	15.4	2.3	3.9	4.8	100.0
6	TX	AMARILLO	57.5	24.8	3.7	6.3	7.7	100.0
6	TX	AUSTIN	44.5	32.6	4.6	8.3	10.1	100.0
6	TX	BEAUMONT	66.3	19.7	2.9	5.0	6.1	100.0
6	TX	BROWNSVILLE	39.1	35.6	5.2	9.0	11.1	100.0
6	TX	BRYAN	66.3	19.7	2.9	5.0	6.1	100.0
6	TX	CORPUS CHRISTI	64.7	20.6	3.0	5.2	6.4	100.0
6	TX	DALLAS	59.0	23.9	3.5	6.1	7.5	100.0
6	TX	EL PASO	47.1	30.9	4.5	7.8	9.6	100.0
6	TX	FORT WORTH	63.5	21.3	3.1	5.4	6.6	100.0
6	TX	GALVESTON	48.9	29.8	4.4	7.6	9.3	100.0
6	TX	HARLINGEN	67.7	18.9	2.8	4.8	5.8	100.0
6	TX	HOUSTON	43.7	32.9	4.8	8.3	10.2	100.0
6	TX	LAREDO	42.9	33.3	4.9	8.4	10.4	100.0
6	TX	LUBBOCK	59.6	23.6	3.5	6.0	7.4	100.0
6	TX	MCALLEN	48.1	30.3	4.5	7.7	9.5	100.0
6	TX	MIDLAND	60.8	22.9	3.4	5.8	7.1	100.0
6	TX	ODESSA	40.8	34.0	5.0	9.6	10.6	100.0
6	TX	PORT ARTHUR	65.6	20.1	3.0	5.1	6.3	100.0
6	TX	SAN ANGELO	60.7	22.5	3.4	5.8	7.6	100.0
6	TX	SAN ANTONIO	39.9	35.1	5.2	8.9	10.8	100.0
6	TX	SHERMAN	65.9	19.9	2.9	5.1	6.2	100.0
6	TX	TEXARKANA	60.8	22.9	3.4	5.8	7.1	100.0
6	TX	TEXAS CITY	76.4	13.8	2.0	3.5	4.3	100.0
6	TX	TYLER	52.9	27.5	4.1	7.0	8.6	100.0
6	TX	WACO	70.4	17.3	2.5	4.4	5.4	100.0
6	TX	WICHITA FALL	53.8	27.0	4.0	6.8	8.4	100.0
6	TX	OTHER URBAN AREAS	56.0	25.7	3.8	6.5	8.0	100.0
6	TX	AVE. FOR STATE	56.0	25.7	3.8	6.5	8.0	100.0
6		AVE. FOR REGION 6	55.3	26.1	3.8	6.6	8.1	100.0

TABLE III-4 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA REG	STATE ID	URBANIZED AREA	LAND USE AS % OF TOTAL AREA UNDV	RES	COMM	INDL	OTH	TOTAL
7	IA	CEDAR RAPIDS	56.8	25.2	3.7	6.4	7.9	100.0
7	IA	DAVENPORT	69.4	17.9	2.6	4.5	5.6	100.0
7	IA	DES MOINES	53.7	27.0	4.0	6.8	8.4	100.0
7	IA	DUBUQUE	40.3	34.9	5.1	8.8	10.9	100.0
7	IA	SIOUX CITY	65.4	20.2	3.0	5.1	6.3	100.0
7	IA	WATERLOO	64.7	20.6	3.0	5.2	6.4	100.0
7	IA	OTHER URBAN AREAS	60.4	23.1	3.4	5.9	7.2	100.0
7	IA	AVE. FOR STATE	60.4	23.1	3.4	5.9	7.2	100.0
7	KS	KANSAS CITY METRO	42.9	33.3	4.9	8.5	10.4	100.0
7	KS	TOPEKA	51.6	28.3	4.2	7.2	8.8	100.0
7	KS	WICHITA	46.6	31.2	4.6	7.9	9.7	100.0
7	KS	OTHER URBAN AREAS	46.4	31.3	4.6	7.9	9.8	100.0
7	KS	AVE. FOR STATE	46.4	31.3	4.6	7.9	9.8	100.0
7	MO	COLUMBIA	68.9	18.2	2.7	4.5	5.7	100.0
7	MO	KANSAS CITY	58.3	24.4	3.6	6.2	7.6	100.0
7	MO	SPRINGFIELD	60.0	23.3	3.4	5.9	7.3	100.0
7	MO	ST.JOSEPH	29.7	41.1	6.0	10.4	12.8	100.0
7	MO	ST.LOUIS	33.8	38.7	5.7	9.8	12.1	100.0
7	MO	OTHER URBAN AREAS	46.7	31.1	4.6	7.9	9.7	100.0
7	MO	AVE. FOR STATE	46.7	31.1	4.6	7.9	9.7	100.0
7	NE	LINCOLN	45.8	31.7	4.7	8.0	9.9	100.0
7	NE	OMAHA	42.1	33.8	5.0	8.6	10.5	100.0
7	NE	OTHER URBAN AREAS	43.0	33.3	4.9	8.4	10.4	100.0
7	NE	AVE. FOR STATE	43.0	33.3	4.9	8.4	10.4	100.0
7		AVE. FOR REGION 7	50.4	28.9	4.3	7.3	9.0	100.0
8	CO	BOULDER	27.0	42.6	6.3	10.8	13.3	100.0
8	CO	COLORADO SPRINGS	54.6	26.5	3.9	6.7	8.3	100.0
8	CO	DENVER	38.7	35.8	5.3	9.1	11.2	100.0
8	CO	PUEBLO	42.5	33.6	4.9	8.5	10.5	100.0
8	CO	OTHER URBAN AREAS	41.9	33.9	5.0	8.6	10.6	100.0
8	CO	AVE. FOR STATE	41.9	33.9	5.0	8.6	10.6	100.0
8	MT	BILLINGS	49.7	29.4	4.3	7.4	9.1	100.0
8	MT	GREAT FALLS	42.4	33.6	5.0	8.5	10.5	100.0
8	MT	OTHER URBAN AREAS	46.5	31.3	4.6	7.9	9.7	100.0
8	MT	AVE. FOR STATE	46.5	31.3	4.6	7.9	9.7	100.0
8	ND	FARGO	39.2	35.5	5.2	9.0	11.1	100.0
8	ND	OTHER URBAN AREAS	39.2	35.5	5.2	9.0	11.1	100.0
8	ND	AVE. FOR STATE	39.2	35.5	5.2	9.0	11.1	100.0
8	SD	SIOUX FALLS	47.8	30.5	4.5	7.7	9.5	100.0
8	SD	OTHER URBAN AREAS	47.8	30.5	4.5	7.7	9.5	100.0
8	SD	AVE. FOR STATE	47.8	30.5	4.5	7.7	9.5	100.0
8	UT	OGDEN	52.0	28.0	4.1	7.1	8.7	100.0
8	UT	PROVO	65.4	20.2	3.0	5.1	6.3	100.0
8	UT	SALT LAKE CITY	50.1	29.5	4.3	7.4	9.1	100.0
8	UT	OTHER URBAN AREAS	53.7	27.1	4.0	6.9	8.4	100.0
8	UT	AVE. FOR STATE	53.7	27.1	4.0	6.9	8.4	100.0
8	WY	URBAN AREAS	50.0	29.2	4.3	7.4	9.1	100.0
8	WY	AVE. FOR STATE	50.0	29.2	4.3	7.4	9.1	100.0
8		AVE. FOR REGION 8	46.5	31.2	4.6	7.9	9.7	100.0

TABLE III-4 LAND USE DISTRIBUTION FOR THE URBAN AREAS IN THE U.S.

EPA REG	STATE ID	URBANIZED AREA	LAND USE AS % OF TOTAL AREA UNDV	RES	COMM	INDL	OTH	TOTAL
9	AK	URBAN AREAS	60.1	23.3	3.4	5.9	7.3	100.0
9	AK	AVE. FOR STATE	60.1	23.3	3.4	5.9	7.3	100.0
9	AZ	PHOENIX	55.4	26.1	3.8	6.4	8.1	100.0
9	AZ	TUCSON	47.5	30.6	4.5	7.8	9.5	100.0
9	AZ	OTHER URBAN AREAS	53.7	27.0	4.0	6.9	8.4	100.0
9	AZ	AVE. FOR STATE	53.7	27.0	4.0	6.9	8.4	100.0
9	CA	BAKERSFIELD	44.0	32.7	4.8	8.3	10.2	100.0
9	CA	FRESNO	41.3	34.3	5.0	8.7	10.7	100.0
9	CA	LOS ANGELES	24.4	44.2	6.5	11.2	13.8	100.0
9	CA	MODESTO	43.7	32.9	4.8	8.3	10.2	100.0
9	CA	OXNARD	55.9	25.7	3.8	6.5	8.0	100.0
9	CA	SACRAMENTO	50.1	29.1	4.3	7.4	9.1	100.0
9	CA	SALINAS	33.4	38.9	5.7	9.9	12.1	100.0
9	CA	SAN BERNANDINO	60.6	23.0	3.4	5.3	7.6	100.0
9	CA	SAN DIEGO	43.4	33.1	4.9	8.4	10.3	100.0
9	CA	SAN FRANCISCO	31.2	40.2	5.9	10.2	12.5	100.0
9	CA	SAN JOSE	37.4	36.5	5.4	9.3	11.4	100.0
9	CA	SANTA BARBARA	39.3	35.4	5.2	9.0	11.0	100.0
9	CA	SANTA ROSA	59.3	23.8	3.5	6.0	7.4	100.0
9	CA	SEASIDE	35.7	37.5	5.5	9.5	11.7	100.0
9	CA	SIMI VALLEY	54.6	26.5	3.9	6.7	8.3	100.0
9	CA	STOCKTON	40.5	34.8	5.1	8.8	10.6	100.0
9	CA	OTHER URBAN AREAS	35.4	37.7	5.6	9.6	11.8	100.0
9	CA	AVE. FOR STATE	35.4	37.7	5.6	9.6	11.8	100.0
9	HI	HONOLULU	36.0	37.4	5.5	9.5	11.6	100.0
9	HI	OTHER URBAN AREAS	36.0	37.4	5.5	9.5	11.6	100.0
9	HI	AVE. FOR STATE	36.0	37.4	5.5	9.5	11.6	100.0
9	NV	LAS VEGAS	59.4	23.7	3.5	6.0	7.4	100.0
9	NV	RENO	49.7	29.4	4.3	7.4	9.2	100.0
9	NV	OTHER URBAN AREAS	57.1	25.0	3.7	6.3	7.8	100.0
9	NV	AVE. FOR STATE	57.1	25.0	3.7	6.3	7.8	100.0
9		AVE. FOR REGION 9	38.6	35.9	5.3	9.1	11.2	100.0
10	ID	BOISE	45.9	31.6	4.7	8.0	9.8	100.0
10	ID	OTHER URBAN AREAS	45.9	31.6	4.7	8.0	9.8	100.0
10	ID	AVE. FOR STATE	45.9	31.6	4.7	8.0	9.8	100.0
10	OR	EUGENE	51.1	28.6	4.2	7.2	8.9	100.0
10	OR	PORTLAND	44.0	32.7	4.8	8.3	10.2	100.0
10	OR	SALEM	51.3	28.4	4.2	7.2	8.9	100.0
10	OR	OTHER URBAN AREAS	45.8	31.6	4.7	8.0	9.9	100.0
10	OR	AVE. FOR STATE	45.8	31.6	4.7	8.0	9.9	100.0
10	WA	SEATTLE	45.1	32.1	4.7	8.1	10.0	100.0
10	WA	SPOKANE	45.7	31.7	4.7	8.0	9.9	100.0
10	WA	TACOMA	50.5	28.9	4.3	7.3	9.0	100.0
10	WA	OTHER URBAN AREAS	46.3	31.4	4.6	7.9	9.8	100.0
10	WA	AVE. FOR STATE	46.3	31.4	4.6	7.9	9.8	100.0
10		AVE. FOR REGION 10	46.1	31.5	4.6	8.0	9.8	100.0
		AVERAGE FOR THE U.S.	46.2	31.4	4.6	8.0	9.8	100.0

POPULATION AND AREA SERVED BY TYPE OF SEWER SYSTEM

Combined Sewers

Two data sources were used to determine the estimated population served by combined sewers for the 50 metropolitan areas studied in detail. Population and area estimates were taken from a 1968 Inventory of Municipal Waste Facilities, done by USEPA.[4] The inventory lists contributory population to each treatment facility and identifies those facilities served in whole or in part by combined sewers.

The second source of data was a 1967 inventory conducted by the APWA for USEPA of local authorities with combined sewer systems.[5] For that survey, personal interviews were conducted at over 640 authorities which were selected. Where large variations were evident, the local City Engineer was asked to verify the population estimate. In all cases, the population thus obtained was approximately the same as the APWA estimate - indicating that the 1968 inventory figures were for the total contributory to the facility.

The population estimate which was used consisted of the APWA survey for each city with data and the total population given by the 1968 inventory for cities not surveyed by APWA with a population less than 25,000. Thus, the total used may be somewhat larger than the actual.

Area served by combined sewers was projected at the same population density as for the core cities for which data were available. This would underestimate the total area if the correct population estimate was available, but is compensated for by the overpopulation estimate. If the calculated population density for the combined sewered areas was less than the storm sewer population density, then the two densities were equated by adjusting the area served by combined sewers.

The above results permit determination of the proportion of the urban area served by combined sewers. These results are extrapolated to the state level by assuming that the population and area served by combined sewers is the same for the rest of the state.

Separately Sewered and Unsewered Areas

Information was obtained regarding the population density distributions of the fifty cities.[6] Using these data, the census tracts were ranked by population density and grouped into five categories ranging from lowest density to highest density. A histogram for the City of Albany, New York, is shown in Figure III-4, Population Density Distribution of Albany, New York.

An equation of the form

$$PD = ax^{b} \qquad \text{(III-3)}$$

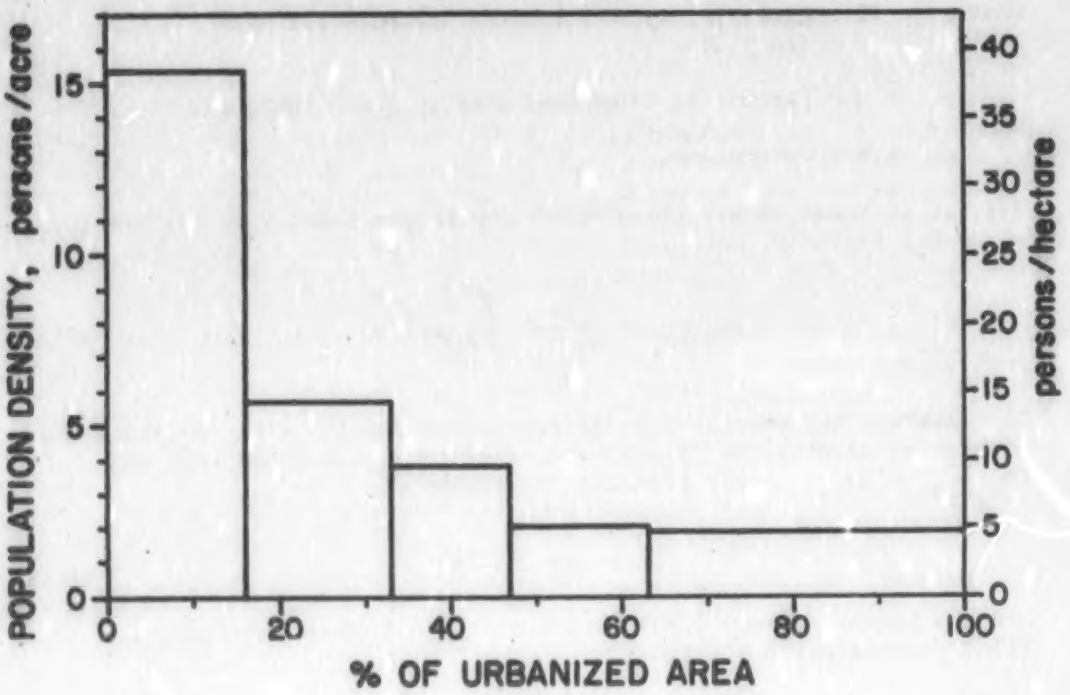

Figure III-4. Population Density Distribution of Albany, New York

where PD = gross population density, persons per acre ($PD \geq 0$),

x = percent of urbanized area ($0 \leq x \leq 100$), and

a,b = parameters,

was fit to these data. The average population density in any interval, x_1 to x_2, is

$$PD_{x_1-x_2} = \frac{1}{x_2-x_1} \int_{x_1}^{x_2} ax^b dx. \qquad \text{(III-4)}$$

To calibrate the overall average population density with the calculated population density, an approximate value of x_1 was found such that $PD_{x_1-100} = PD_{calc}$. For example, for Albany,

$$PD = 108\ x^{-0.933} \qquad \text{(III-5)}$$

and the actual average population density is 5.03 persons per acre (12.4 persons per ha). Thus,

$$5.03 = \frac{1}{100-x_1} \int_{x_1}^{100} 108\ x^{-0.933} dx. \qquad \text{(III-6)}$$

This equation is solved to find x_1. To calibrate the overall average population density with the calculated population density, for the other 198 cities, values of b were assigned based on their similarity to the five test cities. A value of $x_1 = 2$ was used to avoid instability problems. Then, a was calculated such that the average population density, PD_{2-100}, is

$$PD_{2-100} = \frac{1}{100-2} \int_{2}^{100} ax^b dx, \qquad \text{(III-7)}$$

or

$$a = \frac{98\ PD(1+b)}{100^{(1+b)} - 2^{(1+b)}}. \qquad \text{(III-8)}$$

Thus, the final equation for gross population density is

$$PD = ax^b \text{ with } x_1 \leq x \leq 100. \qquad \text{(III-9)}$$

Given the equation in the form $PD = ax^b$, one can find the average population density, the proportion of the population within certain densities and so forth.

The method for determining which of the 50 cities would be selected for the city in question was as follows. All 50 cities were divided into their respective USEPA regions. The mean and standard deviation of the population, land area, and population density were determined. Then a range of acceptable values was found for these parameters within each USEPA region.

For each city in question, two approaches were used in selecting the appropriate reference test city. First, all test cities in the same USEPA region as the city in question that fell within the described range were listed. Second, those test cities outside the respective USEPA region that fell within 10 percent of the mean values for the parameters of the city in question were listed. The order of priority in selecting the reference test city was as follows:

1. proximity of population density and land area in same USEPA region; and
2. proximity of population density and land area outside USEPA region.

In selecting the "best" reference test city, location and land area were the dominant factors because they have a definite influence on population density. Similar location implies that the city in question would probably have developed at the same time and have been influenced by similar national population shifts, manufacturing technologies, urban growth patterns, etc. Land area was chosen simply because population density is a function of the size of the urbanized area. For the above reasons, the majority of the cities in question were referenced to a test city outside their respective USEPA region.

The population density function, $PD = ax^b$, is given in terms of the total urbanized area. Thus, it needs to be modified to integrate over only the developed portion of the urban area as shown in Figure III-5, Characterization of Population Density in Urban Areas. In order for the area under the two curves to be equal, one must have that

$$\int_{x_1}^{100} ax^b dx = \int_{x_1}^{100(1-Z)} a'x^b dx \qquad \text{(III-10)}$$

or

$$a' = a[100^{(1+b)} - x_1^{(1+b)}]/[(100(1-Z))^{(1+b)} - x_1^{(1+b)}]. \qquad \text{(III-11)}$$

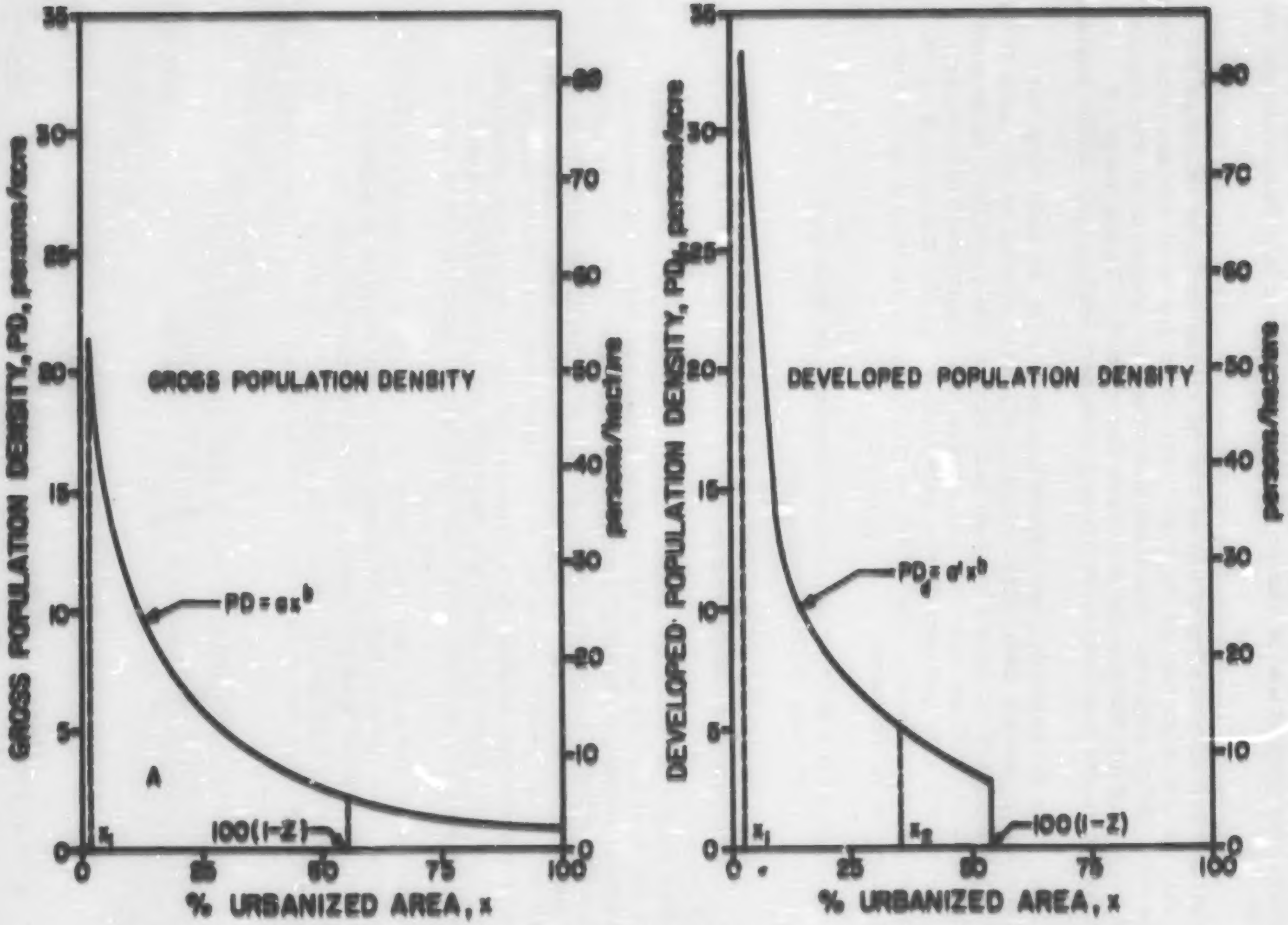

Figure III-5. Characterization of Population Density in Urban Areas

Then,

$$PD_d = a'x_1^b \qquad \text{(III-12)}$$

where PD_d = population density in developed portion of the urban area,

a' = adjusted coefficient from equation III-11, and

x_1 = calibrated lower limit on percent urbanized area.

The percent of the urban area which is sewered is known for the nine Ontario cities. Computing the corresponding PD_d for seven of the cities resulted in the values shown in Table III-5, Minimum Population Density for Sewered Portion of Seven Urbanized Areas in Ontario. Guelph and West Toronto were considered extreme values and not entered into Table III-5. Based on these data, a cutoff minimum developed population density of five persons per acre (12.4 persons per ha) was used to delineate the sewered part of the urban area. Solving equation III-12 for x_2 yields

$$x_2 = \min\ [(5/a)^{1/b},\ 100(1-Z)] \qquad \text{(III-13)}$$

where x_2 = percent of the urban area which is sewered.

Knowing the percent of the urbanized area which is undeveloped, i.e., 100Z, the combined sewered area from the survey data and the percent of the urban area which is sewered, x_2, then the other sewered and unsewered developed areas can be calculated as residuals. The calculation procedure is summarized below:

Sewered Areas as a Percentage of Total Urbanized Area

1. Undeveloped Area = 100(Z) = x_u
2. Sewered Area = x_2
3. Combined Sewer Area = x_c, from APWA data
4. Storm Sewer Area = $x_2 - x_c$
5. Unsewered Developed Area = $100 - x_u - x_2$

Table III-5. MINIMUM POPULATION DENSITY FOR SEWERED PORTION OF SEVEN URBANIZED AREAS IN ONTARIO[2]

City	Minimum Sewered Population Density, PD_d (persons/acre)	(persons/ha)
Burlington	3.93	9.7
Kingston	7.28	18.0
Kitchener	4.49	11.1
St. Catharines	5.79	14.3
Sault Ste. Marie	4.67	11.5
Thunder Bay	6.12	15.1
Windsor	3.87	9.6
Average of 7 cities	5.16	12.8

The results of these calculations are shown in Table III-6, Land Use by Type of Sewerage System.

The population served by combined sewerage systems is estimated directly from the APWA data. Combined sewers are found in the older and typically more densely populated portions of the urbanized areas. This fact suggests that a good approximation of the population would be obtained by assuming that the higher density areas are combined. The next highest density is served by storm sewers and the lowest densities are unsewered. Thus, the population served by type of sewer system is calculated as shown below:

Population Served by Type of Sewerage System

1. Combined Sewers (P_c):

$$P_c = \text{APWA estimate}$$

TABLE III-6 LAND USE BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	AREA SERVED BY TYPE OF SYSTEM 1000 ACRES UNDV	COMB	STORM	UNSEW	TOTAL
1	CT	BRIDGEPORT	45.7	5.8	17.3	26.6	95.4
1	CT	BRISTOL	14.1	0.0	3.7	5.9	23.7
1	CT	DANBURY	25.5	0.0	3.5	6.2	35.2
1	CT	HARTFORD	[illegible]	20.8	6.1	24.5	[illegible]
1	CT	MERIDEN	31.5	0.0	5.1	8.4	45.4
1	CT	NEW BRITAIN	10.2	0.0	8.6	6.1	25.0
1	CT	NEW HAVEN	28.6	14.8	6.4	18.3	68.3
1	CT	NORWALK	13.7	1.5	4.2	7.5	26.9
1	CT	STAMFORD	25.2	0.0	10.3	12.5	48.8
1	CT	WATERBURY	19.2	1.8	6.8	10.9	38.4
1	CT	OTHER URBAN AREAS	35.9	6.6	10.6	18.7	71.8
1	CT	TOTAL FOR STATE	279.4	51.4	82.7	145.4	558.8
1	ME	LEWISTON	33.8	4.7	0.0	5.1	43.5
1	ME	PORTLAND	21.7	10.3	0.0	3.9	35.8
1	ME	OTHER URBAN AREAS	108.9	29.4	0.0	17.6	155.9
1	ME	TOTAL FOR STATE	164.4	44.4	0.0	26.5	235.3
1	MA	BOSTON	147.1	21.2	113.7	142.9	425.0
1	MA	BROCKTON	16.1	0.0	8.4	9.5	33.9
1	MA	FALL RIVER	11.9	7.3	0.8	7.8	27.5
1	MA	FITCHBURG	27.8	1.7	2.4	7.2	39.0
1	MA	LAWRENCE	[illegible]	12.0	0.0	13.5	[illegible]
1	MA	LOWELL	18.1	6.2	3.5	11.9	39.7
1	MA	NEW BEDFORD	7.6	8.9	0.8	4.4	21.8
1	MA	PITTSFIELD	14.3	0.0	3.3	5.7	23.2
1	MA	SPRINGFIELD	85.8	32.9	0.0	33.6	152.3
1	MA	WORCESTER	24.6	2.1	12.5	14.6	53.8
1	MA	OTHER URBAN AREAS	40.3	9.6	15.1	26.1	91.1
1	MA	TOTAL FOR STATE	426.9	101.8	160.5	276.8	966.0
1	NH	MANCHESTER	13.1	7.0	0.0	4.9	25.0
1	NH	NASHUA	13.5	4.9	0.0	3.4	21.8
1	NH	OTHER URBAN AREAS	44.5	19.9	0.0	13.8	78.2
1	NH	TOTAL FOR STATE	71.1	31.7	0.0	22.1	124.9
1	RI	PROVIDENCE	65.7	21.0	23.0	46.4	156.2
1	RI	OTHER URBAN AREAS	2.6	0.8	0.9	1.8	6.1
1	RI	TOTAL FOR STATE	68.3	21.8	23.9	48.2	162.2
1	VT	URBAN AREAS	17.1	7.9	0.0	9.6	34.6
1	VT	TOTAL FOR STATE	17.1	7.9	0.0	9.6	34.6
1		TOTAL FOR REGION 1	1027.1	259.1	267.0	528.5	2081.8
2	NJ	ATLANTIC CITY	25.2	0.0	6.8	10.9	42.9
2	NJ	NEW YORK CITY METRO	625.2	6.2	270.0	407.4	1308.8
2	NJ	PHILADELPHIA METRO	10.5	20.3	0.0	0.6	31.4
2	NJ	TRENTON	13.6	0.0	20.8	7.2	41.6
2	NJ	VINELAND	43.2	0.0	3.9	7.3	54.4
2	NJ	TOTAL FOR STATE	717.6	26.5	301.5	433.4	1479.0
2	NY	ALBANY	41.1	19.3	6.7	29.5	96.6
2	NY	BINGHAMPTON	14.2	15.2	0.0	3.9	33.3
2	NY	BUFFALO	35.6	38.3	32.4	30.7	137.0
2	NY	NEW YORK CITY	0.2	108.3	134.7	0.0	243.2
2	NY	ROCHESTER	31.5	14.3	14.4	33.6	93.8
2	NY	SYRACUSE	21.7	13.9	11.7	14.8	61.4
2	NY	UTICA	25.4	2.5	7.8	13.0	48.0
2	NY	OTHER URBAN AREAS	27.7	34.9	33.9	20.5	116.7
2	NY	TOTAL FOR STATE	197.1	245.6	241.1	145.9	829.7
2		TOTAL FOR REGION 2	914.8	272.1	542.6	579.2	2308.7

TABLE III-6 LAND USE BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	AREA SERVED BY TYPE OF SYSTEM 1000 ACRES UNDV	COMB	STORM	UNSEW	TOTAL
3	DE	WILMINGTON	28.7	6.0	16.2	19.1	70.4
3	DE	OTHER URBAN AREAS	1.9	0.8	1.0	1.2	4.6
3	DE	TOTAL FOR STATE	30.6	6.8	17.2	20.3	75.0
3	DC	WASHINGTON,D.C.	1.5	12.7	25.1	0.0	39.3
3	DC	TOTAL FOR STATE	1.5	12.7	25.1	0.0	39.3
3	MD	BALTIMORE	51.2	0.0	103.0	44.2	198.4
3	MD	WASHINGTON DC METRO	27.0	0.0	27.2	22.7	76.8
3	MD	OTHER URBAN AREAS	36.3	0.0	60.4	31.0	127.6
3	MD	TOTAL FOR STATE	114.5	0.0	190.5	97.9	402.8
3	PA	ALLENTOWN	23.9	0.4	20.5	18.6	63.4
3	PA	ALTOONA	8.3	1.5	4.6	2.4	16.8
3	PA	ERIE	9.8	4.4	8.4	5.6	[illegible]
3	PA	HARRISBURG	22.0	0.8	12.4	15.8	[illegible]
3	PA	JOHNSTOWN	7.2	2.1	3.5	3.8	[illegible]
3	PA	LANCASTER	11.3	4.8	2.4	6.5	25.0
3	PA	PHILADELPHIA	[illegible]	10.9	260.2	72.6	[illegible]
3	PA	PITTSBURGH	167.5	31.5	40.4	142.0	381.4
3	PA	READING	8.8	0.0	12.5	4.9	[illegible]
3	PA	SCRANTON	36.1	17.1	0.0	9.5	62.7
3	PA	WILKES-BARRE	26.0	5.9	6.6	14.6	53.1
3	PA	YORK	9.8	0.0	8.8	5.3	[illegible]
3	PA	OTHER URBAN AREAS	56.6	10.3	49.9	39.3	156.1
3	PA	TOTAL FOR STATE	489.5	89.3	432.0	339.5	1350.4
3	VA	LYNCHBERG	13.3	10.4	0.0	0.0	23.7
3	VA	NEWPORT NEWS	55.6	0.0	13.7	[illegible]	91.5
3	VA	NORFOLK	105.7	0.0	33.3	52.3	191.4
3	VA	PETERSBURG	14.2	0.0	5.0	7.7	26.9
3	VA	RICHMOND	43.3	15.9	7.3	26.3	[illegible]
3	VA	ROANOKE	25.5	0.3	8.0	11.5	[illegible]
3	VA	WASHINGTON DC METRO	[illegible]	1.5	86.9	0.0	[illegible]
3	VA	OTHER URBAN AREAS	0.1	0.0	0.1	0.0	0.2
3	VA	TOTAL FOR STATE	266.8	28.0	154.3	120.0	569.2
3	WV	CHARLESTON	20.2	6.8	1.9	10.9	39.7
3	WV	HUNTINGTON	8.4	14.8	0.0	0.0	[illegible]
3	WV	STEUBENVILLE METRO	10.5	6.6	0.0	0.0	[illegible]
3	WV	WHEELING	[illegible]	6.7	0.3	8.5	[illegible]
3	WV	OTHER URBAN AREAS	30.2	27.7	1.4	4.3	63.7
3	WV	TOTAL FOR STATE	76.7	57.6	3.5	23.7	161.6
3		TOTAL FOR REGION 3	979.6	194.5	822.6	601.4	2598.2

TABLE III-6 LAND USE BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	AREA SERVED BY TYPE OF SYSTEM 1000 ACRES UNDV	COMB	STORM	UNSEW	TOTAL
4	AL	BIRMINGHAM	74.5	0.0	30.4	39.0	144.0
4	AL	GADSDEN	25.3	0.0	3.5	[illegible]	[illegible]
4	AL	HUNTSVILLE	57.4	0.0	7.8	[illegible]	[illegible]
4	AL	MOBILE	71.5	0.0	13.0	[illegible]	[illegible]
4	AL	MONTGOMERY	15.8	0.0	7.0	[illegible]	[illegible]
4	AL	TUSCALOOSA	16.0	0.0	5.0	[illegible]	[illegible]
4	AL	OTHER URBAN AREAS	157.5	0.0	34.5	59.8	[illegible]
4	AL	TOTAL FOR STATE	418.8	0.0	105.1	159.1	683.0
4	FL	FT.LAUDERDALE	62.9	0.0	33.7	39.1	135.7
4	FL	GAINESVILLE	8.9	0.0	3.6	[illegible]	[illegible]
4	FL	JACKSONVILLE	150.4	0.0	26.2	[illegible]	[illegible]
4	FL	MIAMI	87.4	0.0	41.2	[illegible]	[illegible]
4	FL	ORLANDO	65.7	0.3	13.1	[illegible]	[illegible]
4	FL	PENSACOLA	21.6	0.0	[illegible]	[illegible]	[illegible]
4	FL	ST.PETERSBURG	45.5	0.0	[illegible]	[illegible]	[illegible]
4	FL	TALLAHASSEE	8.6	0.0	[illegible]	[illegible]	[illegible]
4	FL	TAMPA	39.7	0.0	18.3	[illegible]	[illegible]
4	FL	WEST PALM BEACH	29.6	0.0	[illegible]	[illegible]	[illegible]
4	FL	OTHER URBAN AREAS	155.1	0.1	75.8	79.2	[illegible]
4	FL	TOTAL FOR STATE	637.4	0.4	311.6	325.3	1274.7
4	GA	ALBANY	9.1	12.0	0.0	0.0	[illegible]
4	GA	ATLANTA	136.0	9.5	55.6	[illegible]	[illegible]
4	GA	AUGUSTA	13.8	9.0	0.0	[illegible]	[illegible]
4	GA	COLUMBUS	40.2	6.5	3.5	17.9	[illegible]
4	GA	MACON	16.8	0.0	7.0	[illegible]	[illegible]
4	GA	SAVANNAH	20.7	6.5	2.4	[illegible]	[illegible]
4	GA	OTHER URBAN AREAS	110.5	18.4	32.3	57.1	[illegible]
4	GA	TOTAL FOR STATE	352.1	60.2	102.7	181.8	696.9
4	KY	HUNTINGTON METRO	6.7	0.0	1.8	3.5	[illegible]
4	KY	LEXINGTON	8.8	0.0	11.6	[illegible]	[illegible]
4	KY	LOUISVILLE	55.8	1.6	36.3	41.7	[illegible]
4	KY	OWENSBORO	2.9	3.5	0.7	[illegible]	7.7
4	KY	OTHER URBAN AREAS	48.7	4.6	35.9	35.6	124.2
4	KY	TOTAL FOR STATE	119.4	9.6	88.1	87.4	304.4
4	MS	BILOXI	24.8	0.0	5.5	[illegible]	41.0
4	MS	JACKSON	22.9	0.0	10.7	[illegible]	[illegible]
4	MS	OTHER URBAN AREAS	103.6	0.0	35.3	50.3	[illegible]
4	MS	TOTAL FOR STATE	151.2	0.0	51.5	73.5	276.2
4	NC	ASHEVILLE	14.7	0.0	3.7	[illegible]	[illegible]
4	NC	CHARLOTTE	33.6	0.0	15.8	[illegible]	[illegible]
4	NC	DURHAM	14.7	0.0	[illegible]	[illegible]	[illegible]
4	NC	FAYETTEVILLE	26.0	0.0	[illegible]	[illegible]	[illegible]
4	NC	GREENSBORO	30.1	0.0	[illegible]	[illegible]	[illegible]
4	NC	HIGHPOINT	20.6	0.0	[illegible]	[illegible]	[illegible]
4	NC	RALEIGH	25.7	0.0	[illegible]	[illegible]	[illegible]
4	NC	WILMINGTON	10.9	0.0	[illegible]	[illegible]	[illegible]
4	NC	WINSTON-SALEM	23.9	0.0	7.0	[illegible]	[illegible]
4	NC	OTHER URBAN AREAS	168.8	0.0	53.5	83.7	306.0
4	NC	TOTAL FOR STATE	359.1	0.0	113.7	178.1	650.9
4	SC	CHARLESTON	34.4	0.0	11.6	[illegible]	[illegible]
4	SC	COLUMBIA	35.3	0.0	[illegible]	[illegible]	[illegible]
4	SC	GREENVILLE	25.3	0.0	7.0	[illegible]	[illegible]
4	SC	OTHER URBAN AREAS	91.8	0.0	30.5	46.6	168.9
4	SC	TOTAL FOR STATE	186.7	0.0	62.1	94.8	343.6
4	TN	CHATTANOOGA	45.0	2.3	8.8	18.8	74.9
4	TN	KNOXVILLE	30.6	0.0	[illegible]	[illegible]	[illegible]
4	TN	MEMPHIS	51.0	0.0	35.7	[illegible]	[illegible]
4	TN	NASHVILLE	[illegible]	12.7	11.5	38.2	[illegible]
4	TN	OTHER URBAN AREAS	144.5	10.7	35.4	56.9	[illegible]
4	TN	TOTAL FOR STATE	427.0	25.7	98.8	167.5	718.9
4		TOTAL FOR REGION 4	2651.8	95.9	933.6	1267.4	4948.6

TABLE III-6 LAND USE BY TYPE OF SEWERAGE SYSTEM

EPA RFG	STATE ID	URBANIZED AREA	AREA SERVED BY TYPE OF SYSTEM 1000 ACRES				
			UNDV	COMB	STORM	UNSEW	TOTAL
5	IL	AURORA	22.1	0.0	[illegible]	[illegible]	[illegible]
5	IL	BLOOMINGTON	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	IL	CHAMPAIGN	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	IL	CHICAGO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	IL	DAVENPORT METRO	[illegible]	9.7	[illegible]	[illegible]	[illegible]
5	IL	DECATUR	11.6	6.5	0.0	[illegible]	[illegible]
5	IL	JOLIET	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	IL	PEORIA	37.1	14.4	0.0	[illegible]	[illegible]
5	IL	ROCKFORD	15.6	0.0	[illegible]	[illegible]	[illegible]
5	IL	SPRINGFIELD	8.5	2.9	[illegible]	[illegible]	[illegible]
5	IL	OTHER URBAN AREAS	80.2	72.0	51.3	75.5	[illegible]
5	IL	TOTAL FOR STATE	341.9	304.9	218.5	321.9	1189.1
5	IN	ANDERSON	7.5	20.0	0.0	0.0	27.5
5	IN	CHICAGO METRO	76.7	32.3	21.7	[illegible]	[illegible]
5	IN	EVANSVILLE	10.4	15.8	[illegible]	[illegible]	[illegible]
5	IN	FORT WAYNE	18.9	8.1	[illegible]	[illegible]	[illegible]
5	IN	INDIANAPOLIS	137.7	34.0	[illegible]	[illegible]	[illegible]
5	IN	LAFAYETTE	4.0	5.0	[illegible]	[illegible]	[illegible]
5	IN	MUNCIE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	IN	SOUTH BEND	31.4	20.2	0.0	14.4	[illegible]
5	IN	TERRE HAUTE	10.5	0.0	4.0	6.1	[illegible]
5	IN	OTHER URBAN AREAS	61.4	28.1	9.6	31.3	[illegible]
5	IN	TOTAL FOR STATE	366.3	167.9	57.3	186.6	778.1
5	MI	ANN ARBOR	10.0	0.0	13.1	5.7	28.8
5	MI	BAY CITY	7.5	8.3	0.6	[illegible]	[illegible]
5	MI	DETROIT	186.5	164.2	67.4	[illegible]	[illegible]
5	MI	FLINT	24.7	1.1	[illegible]	[illegible]	[illegible]
5	MI	GRAND RAPIDS	49.2	[illegible]	13.5	[illegible]	[illegible]
5	MI	JACKSON	13.0	[illegible]	0.0	[illegible]	[illegible]
5	MI	KALAMAZOO	26.9	0.0	[illegible]	[illegible]	[illegible]
5	MI	LANSING	20.2	7.2	[illegible]	[illegible]	[illegible]
5	MI	MUSKEGON	[illegible]	0.0	5.5	[illegible]	[illegible]
5	MI	SAGINAW	11.5	11.5	0.0	[illegible]	[illegible]
5	MI	OTHER URBAN AREAS	58.0	33.3	22.2	42.1	155.7
5	MI	TOTAL FOR STATE	406.8	233.8	156.0	295.4	1092.0
5	MN	DULUTH	30.7	2.6	2.7	9.5	45.5
5	MN	FARGO METRO	[illegible]	[illegible]	0.4	[illegible]	[illegible]
5	MN	MINNEAPOLIS	[illegible]	31.2	[illegible]	[illegible]	[illegible]
5	MN	ROCHESTER	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	MN	OTHER URBAN AREAS	93.6	11.9	24.5	43.1	[illegible]
5	MN	TOTAL FOR STATE	376.6	47.9	98.1	172.9	695.5
5	OH	AKRON	[illegible]	0.0	[illegible]	37.6	[illegible]
5	OH	CANTON	21.2	1.3	11.7	[illegible]	[illegible]
5	OH	CINCINNATI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	OH	CLEVELAND	184.7	39.2	[illegible]	[illegible]	[illegible]
5	OH	COLUMBUS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	OH	DAYTON	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	OH	HAMILTON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	OH	LIMA	7.2	10.1	0.0	0.0	[illegible]
5	OH	LORAIN	[illegible]	0.1	[illegible]	[illegible]	[illegible]
5	OH	MANSFIELD	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	OH	SPRINGFIELD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	OH	STEUBENVILLE	3.0	4.2	0.0	[illegible]	[illegible]
5	OH	TOLEDO	[illegible]	[illegible]	11.9	[illegible]	[illegible]
5	OH	YOUNGSTOWN	36.6	13.7	[illegible]	[illegible]	[illegible]
5	OH	OTHER URBAN AREAS	119.4	37.5	96.6	[illegible]	[illegible]
5	OH	TOTAL FOR STATE	775.7	211.2	237.6	489.0	1713.6
5	WI	APPLETON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	WI	DULUTH METRO	20.5	0.0	[illegible]	[illegible]	[illegible]
5	WI	GREEN BAY	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	WI	KENOSHA	[illegible]	1.4	[illegible]	[illegible]	[illegible]
5	WI	LA CROSSE	[illegible]	0.5	[illegible]	[illegible]	[illegible]
5	WI	MADISON	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	WI	MILWAUKEE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	WI	OSHKOSH	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	WI	RACINE	[illegible]	0.0	[illegible]	[illegible]	[illegible]
5	WI	OTHER URBAN AREAS	[illegible]	[illegible]	41.8	[illegible]	[illegible]
5	WI	TOTAL FOR STATE	341.9	31.8	144.4	170.0	688.2
5		TOTAL FOR REGION 5.	2609.2	999.5	912.0	1635.8	6156.6

TABLE III-6 LAND USE BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	AREA SERVED BY TYPE OF SYSTEM 1000 ACRES UNDV	COMB	STORM	UNSEW	TOTAL
6	AR	FORT SMITH	27.4	4.3	0.0	6.6	38.4
6	AR	LITTLE ROCK	32.6	0.0	7.5	20.7	60.8
6	AR	PINE BLUFF	6.2	0.0	3.7	3.5	13.4
6	AR	OTHER URBAN AREAS	110.8	7.3	18.8	51.6	188.4
6	AR	TOTAL FOR STATE	177.0	11.6	30.1	82.4	301.0
6	LA	BATON ROUGE	25.0	0.0	14.3	15.1	54.4
6	LA	LAFAYETTE	7.0	0.0	5.1	3.9	16.0
6	LA	LAKE CHARLES	10.9	0.0	4.9	5.9	21.8
6	LA	MONROE	14.1	0.0	3.8	7.7	25.6
6	LA	NEW ORLEANS	2.6	0.0	51.2	0.0	53.8
6	LA	SHREVEPORT	31.1	0.0	12.6	16.5	60.2
6	LA	OTHER URBAN AREAS	37.6	0.0	38.1	20.3	96.0
6	LA	TOTAL FOR STATE	128.2	0.0	130.0	69.5	327.7
6	NM	ALBUQUERQUE	36.5	0.0	16.0	20.4	73.0
6	NM	OTHER URBAN AREAS	50.9	0.0	22.3	28.5	101.7
6	NM	TOTAL FOR STATE	87.4	0.0	38.3	48.9	174.7
6	OK	LAWTON	15.8	0.0	3.9	8.4	28.2
6	OK	OKLAHOMA CITY	137.7	0.0	29.5	49.7	217.0
6	OK	TULSA	66.6	0.0	19.3	29.3	115.2
6	OK	OTHER URBAN AREAS	145.7	0.0	34.9	57.9	238.5
6	OK	TOTAL FOR STATE	365.8	0.0	87.6	145.3	598.8
6	TX	ABILENE	36.7	0.0	4.8	8.4	49.9
6	TX	AMARILLO	22.5	0.0	6.6	10.0	39.0
6	TX	AUSTIN	24.4	0.0	15.9	14.8	55.0
6	TX	BEAUMONT	31.8	2.8	3.1	10.2	48.0
6	TX	BROWNSVILLE	3.8	0.0	4.4	1.5	9.6
6	TX	BRYAN	14.0	0.0	2.6	4.5	21.1
6	TX	CORPUS CHRISTI	53.8	0.0	10.9	18.5	83.2
6	TX	DALLAS	254.6	0.0	74.2	102.6	431.4
6	TX	EL PASO	35.9	0.0	18.2	22.1	76.2
6	TX	FORT WORTH	160.9	0.0	34.5	58.0	253.4
6	TX	GALVESTON	7.2	1.1	2.5	4.0	14.7
6	TX	HARLINGEN	14.7	0.0	1.2	5.9	21.8
6	TX	HOUSTON	150.9	0.0	106.5	87.6	345.0
6	TX	LAREDO	6.0	0.0	4.7	3.3	14.1
6	TX	LUBBOCK	29.4	0.0	7.0	12.9	49.3
6	TX	MCALLEN	10.2	0.0	5.2	5.8	21.1
6	TX	MIDLAND	12.4	0.0	2.0	6.1	20.5
6	TX	ODESSA	6.7	0.0	5.7	3.7	16.0
6	TX	PORT ARTHUR	30.6	0.0	4.7	11.4	46.7
6	TX	SAN ANGELO	13.2	0.0	2.1	6.4	21.8
6	TX	SAN ANTONIO	56.9	0.0	41.6	44.2	142.7
6	TX	SHERMAN	14.8	0.0	1.4	6.2	22.4
6	TX	TEXARKANA	12.1	0.0	1.9	5.8	19.8
6	TX	TEXAS CITY	40.6	0.0	4.4	8.1	53.1
6	TX	TYLER	8.5	0.0	3.2	4.4	16.0
6	TX	WACO	40.5	0.0	6.2	10.9	57.6
6	TX	WICHITA FALL	14.5	0.0	4.4	8.0	26.9
6	TX	OTHER URBAN AREAS	319.2	1.1	109.5	139.8	569.7
6	TX	TOTAL FOR STATE	1426.8	5.1	489.3	624.8	2546.0
6		TOTAL FOR REGION 6	2185.2	16.7	775.3	970.9	3948.2

TABLE III-6 LAND USE BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	AREA SERVED BY TYPE OF SYSTEM 1000 ACRES UNDV	COMB	STORM	UNSEW	TOTAL
7	IA	CEDAR RAPIDS	22.5	0.0	6.5	10.6	39.7
7	IA	DAVENPORT	36.8	0.3	5.4	10.5	53.0
7	IA	DES MOINES	37.5	4.0	10.1	18.2	69.8
7	IA	DUBUQUE	4.9	0.0	5.1	2.2	12.2
7	IA	SIOUX CITY	25.1	0.0	4.9	8.4	38.4
7	IA	WATERLOO	26.6	0.0	6.7	10.9	44.2
7	IA	OTHER URBAN AREAS	168.4	4.6	39.8	65.9	278.7
7	IA	TOTAL FOR STATE	323.8	8.9	76.5	126.7	535.9
7	KS	KANSAS CITY METRO	23.6	6.4	10.4	14.6	55.0
7	KS	TOPEKA	17.5	3.7	3.4	9.3	33.9
7	KS	WICHITA	31.3	0.0	18.1	17.8	67.2
7	KS	OTHER URBAN AREAS	79.5	11.1	35.0	45.8	171.4
7	KS	TOTAL FOR STATE	151.9	21.3	66.8	87.6	327.5
7	MO	COLUMBIA	18.5	0.0	3.1	5.3	26.9
7	MO	KANSAS CITY	151.7	21.0	17.8	69.9	260.5
7	MO	SPRINGFIELD	24.2	0.0	6.1	10.0	40.3
7	MO	ST. JOSEPH	6.1	14.4	0.0	0.0	20.5
7	MO	ST. LOUIS	99.7	112.7	0.0	82.6	295.0
7	MO	OTHER URBAN AREAS	31.4	15.5	2.8	17.5	67.2
7	MO	TOTAL FOR STATE	331.6	163.6	29.8	185.4	710.4
7	NE	LINCOLN	15.2	0.0	8.4	9.6	33.3
7	NE	OMAHA	40.7	20.9	5.3	29.8	96.6
7	NE	OTHER URBAN AREAS	23.2	8.7	5.7	16.4	54.0
7	NE	TOTAL FOR STATE	79.1	29.6	19.4	55.8	183.9
7		TOTAL FOR REGION 7	886.4	223.3	192.6	455.5	1757.7
8	CO	BOULDER	2.4	0.0	4.6	1.9	9.0
8	CO	COLORADO SPRINGS	31.5	0.0	10.5	15.6	57.6
8	CO	DENVER	72.6	0.3	59.8	54.9	187.5
8	CO	PUEBLO	8.7	1.2	5.5	5.1	20.5
8	CO	OTHER URBAN AREAS	25.3	0.3	17.7	17.0	60.3
8	CO	TOTAL FOR STATE	140.5	1.8	98.1	94.5	334.9
8	MT	BILLINGS	8.6	0.0	4.0	4.7	17.3
8	MT	GREAT FALLS	6.0	0.0	5.2	2.9	14.1
8	MT	OTHER URBAN AREAS	23.6	0.0	15.0	12.2	50.8
8	MT	TOTAL FOR STATE	38.2	0.0	24.2	19.8	82.2
8	ND	FARGO	3.8	0.2	3.6	2.1	9.8
8	ND	OTHER URBAN AREAS	15.6	0.8	14.8	8.7	39.9
8	ND	TOTAL FOR STATE	19.5	1.0	18.5	10.8	49.7
8	SD	SIOUX FALLS	8.3	0.2	3.8	5.1	17.3
8	SD	OTHER URBAN AREAS	24.5	0.5	11.2	15.0	51.1
8	SD	TOTAL FOR STATE	32.7	0.7	15.0	20.1	68.4
8	UT	OGDEN	20.3	0.0	8.1	10.7	39.0
8	UT	PROVO	27.2	0.0	5.3	9.1	41.6
8	UT	SALT LAKE CITY	59.0	0.0	26.3	32.4	117.8
8	UT	OTHER URBAN AREAS	17.6	0.0	6.6	8.6	32.8
8	UT	TOTAL FOR STATE	124.1	0.0	46.3	60.8	231.2
8	WY	URBAN AREAS	24.6	0.0	11.3	13.4	49.3
8	WY	TOTAL FOR STATE	24.6	0.0	11.3	13.4	49.3
8		TOTAL FOR REGION 8	379.5	3.4	213.3	219.3	815.6

TABLE III-6 LAND USE BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	AREA SERVED BY TYPE OF SYSTEM 1000 ACRES UNDV	COMB	STORM	UNSEW	TOTAL
9	AK	URBAN AREAS	29.6	0.7	6.7	12.1	49.2
9	AK	TOTAL FOR STATE	29.6	0.7	6.7	12.1	49.2
9	AZ	PHOENIX	137.5	0.0	49.6	61.2	248.3
9	AZ	TUCSON	31.9	0.0	16.7	18.6	67.2
9	AZ	OTHER URBAN AREAS	36.8	0.0	14.4	17.3	68.4
9	AZ	TOTAL FOR STATE	206.2	0.0	80.7	97.1	384.0
9	CA	BAKERSFIELD	16.1	0.0	9.8	10.7	36.5
9	CA	FRESNO	20.9	0.0	16.4	13.2	50.6
9	CA	LOS ANGELES	285.4	0.0	548.3	172.5	1006.1
9	CA	MODESTO	9.5	0.0	6.7	5.5	21.7
9	CA	OXNARD	40.1	0.0	12.7	18.9	71.7
9	CA	SACRAMENTO	78.3	5.6	29.7	42.6	156.2
9	CA	SALINAS	3.2	0.0	4.6	1.7	9.6
9	CA	SAN BERNARDINO	120.3	0.0	29.5	48.7	198.5
9	CA	SAN DIEGO	105.8	0.0	67.8	70.6	244.2
9	CA	SAN FRANCISCO	135.9	50.1	80.5	165.3	431.8
9	CA	SAN JOSE	66.3	0.0	55.8	55.1	177.3
9	CA	SANTA BARBARA	9.3	0.0	8.8	5.6	23.7
9	CA	SANTA ROSA	14.4	0.0	2.7	7.3	24.3
9	CA	SEASIDE	5.5	0.0	8.7	1.1	15.3
9	CA	SIMI VALLEY	8.7	0.0	2.9	4.4	16.0
9	CA	STOCKTON	12.2	0.0	10.6	7.3	30.1
9	CA	OTHER URBAN AREAS	110.2	7.4	115.5	77.9	311.0
9	CA	TOTAL FOR STATE	1002.0	67.1	1050.4	708.7	2828.1
9	HI	HONOLULU	26.5	0.0	25.5	21.5	73.6
9	HI	OTHER URBAN AREAS	11.8	0.0	11.3	9.6	32.6
9	HI	TOTAL FOR STATE	38.3	0.0	36.9	31.1	106.2
9	NV	LAS VEGAS	46.0	0.0	12.2	19.2	77.4
9	NV	RENO	12.1	2.4	2.5	7.3	24.3
9	NV	OTHER URBAN AREAS	10.2	0.4	2.6	4.6	17.8
9	NV	TOTAL FOR STATE	68.3	2.8	17.3	31.1	119.6
9		TOTAL FOR REGION 9	1344.4	70.6	1191.9	880.1	3487.0
10	ID	BOISE	8.5	0.0	4.8	5.2	18.6
10	ID	OTHER URBAN AREAS	30.3	0.0	17.1	18.6	65.9
10	ID	TOTAL FOR STATE	38.8	0.0	21.9	23.8	84.5
10	OR	EUGENE	18.0	0.5	7.1	9.6	35.2
10	OR	PORTLAND	75.2	24.2	22.3	49.3	170.9
10	OR	SALEM	12.1	0.0	5.1	6.5	23.7
10	OR	OTHER URBAN AREAS	34.5	8.1	11.3	21.4	75.2
10	OR	TOTAL FOR STATE	139.8	32.7	45.7	86.7	305.0
10	WA	SEATTLE	119.2	37.9	32.7	74.5	264.3
10	WA	SPOKANE	22.8	19.4	0.0	7.7	49.9
10	WA	TACOMA	41.7	0.7	17.3	22.8	82.6
10	WA	OTHER URBAN AREAS	68.9	21.8	18.8	39.4	148.8
10	WA	TOTAL FOR STATE	252.6	79.9	68.8	144.3	545.6
10		TOTAL FOR REGION 10	431.2	112.6	136.5	254.8	935.1
		TOTAL FOR THE U.S.	13409.	2248.	5987.	7393.	29037.

2. Storm Sewers (P_s):

$$P_s = \frac{A}{100} \int_{x_1}^{x_2} a' x^b \, dx - P_c \qquad \text{(III-14)}$$

3. Unsewered (P_u):

$$P_u = P - P_c - P_s \qquad \text{(III-15)}$$

where A = total acreage of urbanized area, and

P = total population of urbanized area.

The resulting population by type of sewerage system is shown in Table III-7, Population by Type of Sewerage System. The population densities by type of sewer system are shown in Table III-8, Developed Population Density by Type of Sewerage System. Lastly, the values of the coefficients used in the above calculations are shown in Table III-9, Values of Coefficients.

TABLE III-7 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	POPULATION SERVED (1000 PERSONS)			
			COMB	STORM	UNSEW	TOTAL
1	CT	BRIDGEPORT	72.	214.	127.	413.
1	CT	BRISTOL	0.	50.	22.	72.
1	CT	DANBURY	0.	42.	25.	67.
1	CT	HARTFORD	275.	81.	109.	465.
1	CT	MERIDEN	0.	64.	34.	98.
1	CT	NEW BRITAIN	0.	97.	34.	131.
1	CT	NEW HAVEN	179.	76.	93.	348.
1	CT	NORWALK	55.	19.	33.	107.
1	CT	STAMFORD	0.	124.	61.	185.
1	CT	WATERBURY	22.	85.	50.	157.
1	CT	OTHER URBAN AREAS	89.	126.	86.	301.
1	CT	TOTAL FOR STATE	692.	979.	673.	2344.
1	ME	LEWISTON	48.	0.	17.	65.
1	ME	PORTLAND	77.	0.	29.	106.
1	ME	OTHER URBAN AREAS	246.	0.	90.	336.
1	ME	TOTAL FOR STATE	372.	0.	135.	507.
1	MA	BOSTON	335.	1798.	519.	2652.
1	MA	BROCKTON	0.	104.	45.	149.
1	MA	FALL RIVER	92.	11.	36.	139.
1	MA	FITCHBURG	21.	29.	28.	78.
1	MA	LAWRENCE	123.	0.	77.	200.
1	MA	LOWELL	87.	48.	48.	183.
1	MA	NEW BEDFORD	101.	9.	24.	134.
1	MA	PITTSFIELD	0.	41.	22.	63.
1	MA	SPRINGFIELD	258.	0.	260.	518.
1	MA	WORCESTER	34.	138.	75.	247.
1	MA	OTHER URBAN AREAS	109.	227.	118.	454.
1	MA	TOTAL FOR STATE	1155.	2404.	1254.	4813.
1	NH	MANCHESTER	71.	0.	24.	95.
1	NH	NASHUA	36.	0.	25.	61.
1	NH	OTHER URBAN AREAS	179.	0.	82.	261.
1	NH	TOTAL FOR STATE	286.	0.	131.	417.
1	RI	PROVIDENCE	333.	247.	195.	795.
1	RI	OTHER URBAN AREAS	13.	10.	8.	31.
1	RI	TOTAL FOR STATE	346.	278.	202.	826.
1	VT	URBAN AREAS	69.	0.	74.	143.
1	VT	TOTAL FOR STATE	69.	0.	74.	143.
1		TOTAL FOR REGION 1	2919.	3641.	2470.	9050.
2	NJ	ATLANTIC CITY	0.	94.	40.	134.
2	NJ	NEW YORK CITY METRO	204.	4102.	1382.	5688.
2	NJ	PHILADELPHIA METRO	201.	0.	1.	202.
2	NJ	TRENTON	0.	234.	40.	274.
2	NJ	VINELAND	0.	42.	32.	74.
2	NJ	TOTAL FOR STATE	405.	4473.	1495.	6372.
2	NY	ALBANY	271.	94.	120.	486.
2	NY	BINGHAMPTON	145.	0.	22.	167.
2	NY	BUFFALO	642.	296.	148.	1086.
2	NY	NEW YORK CITY	6764.	3755.	0.	10519.
2	NY	ROCHESTER	240.	243.	118.	601.
2	NY	SYRACUSE	159.	141.	76.	376.
2	NY	UTICA	30.	85.	65.	180.
2	NY	OTHER URBAN AREAS	1351.	755.	90.	2196.
2	NY	TOTAL FOR STATE	9603.	5369.	639.	15611.
2		TOTAL FOR REGION 2	10007.	9842.	2134.	21983.

TABLE III-7 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	POPULATION SERVED (1000 PERSONS) COMB	STORM	UNSEW	TOTAL
3	DE	WILMINGTON	78.	198.	95.	371.
3	DE	OTHER URBAN AREAS	5.	13.	6.	24.
3	DE	TOTAL FOR STATE	83.	210.	101.	395.
3	DC	WASHINGTON,D.C.	400.	357.	0.	757.
3	DC	TOTAL FOR STATE	400.	357.	0.	757.
3	MD	BALTIMORE	0.	1366.	214.	1580.
3	MD	WASHINGTON DC METRO	0.	373.	100.	473.
3	MD	OTHER URBAN AREAS	0.	806.	146.	952.
3	MD	TOTAL FOR STATE	0.	2545.	460.	3005.
3	PA	ALLENTOWN	5.	276.	[illegible]	364.
3	PA	ALTOONA	17.	[illegible]	[illegible]	[illegible]
3	PA	ERIE	[illegible]	[illegible]	[illegible]	[illegible]
3	PA	HARRISBURG	[illegible]	174.	[illegible]	[illegible]
3	PA	JOHNSTOWN	[illegible]	[illegible]	[illegible]	[illegible]
3	PA	LANCASTER	[illegible]	[illegible]	[illegible]	[illegible]
3	PA	PHILADELPHIA	159.	[illegible]	370.	[illegible]
3	PA	PITTSBURGH	667.	[illegible]	[illegible]	[illegible]
3	PA	READING	0.	[illegible]	[illegible]	[illegible]
3	PA	SCRANTON	148.	0.	[illegible]	[illegible]
3	PA	WILKES-BARRE	71.	80.	[illegible]	[illegible]
3	PA	YORK	0.	[illegible]	[illegible]	[illegible]
3	PA	OTHER URBAN AREAS	157.	671.	148.	[illegible]
3	PA	TOTAL FOR STATE	1354.	5802.	1277.	8433.
3	VA	LYNCHBURG	71.	0.	0.	71.
3	VA	NEWPORT NEWS	0.	175.	[illegible]	[illegible]
3	VA	NORFOLK	0.	[illegible]	[illegible]	[illegible]
3	VA	PETERSBURG	0.	[illegible]	[illegible]	[illegible]
3	VA	RICHMOND	[illegible]	[illegible]	[illegible]	[illegible]
3	VA	ROANOKE	[illegible]	[illegible]	64.	[illegible]
3	VA	WASHINGTON DC METRO	24.	1227.	0.	1251.
3	VA	OTHER URBAN AREAS	0.	1.	0.	1.
3	VA	TOTAL FOR STATE	298.	2143.	492.	2933.
3	WV	CHARLESTON	[illegible]	23.	51.	[illegible]
3	WV	HUNTINGTON	[illegible]	0.	0.	[illegible]
3	WV	STEUBENVILLE METRO	[illegible]	0.	0.	[illegible]
3	WV	WHEELING	[illegible]	[illegible]	23.	[illegible]
3	WV	OTHER URBAN AREAS	283.	17.	[illegible]	[illegible]
3	WV	TOTAL FOR STATE	515.	82.	122.	680.
3		TOTAL FOR REGION 3	2651.	11100.	2451.	16203.

TABLE III-7 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	POPULATION SERVED (1000 PERSONS)			
			COMB	STORM	UNSEW	TOTAL
4	AL	BIRMINGHAM	0.	351.	207.	558.
4	AL	GADSDEN	0.	43.	25.	68.
4	AL	HUNTSVILLE	0.	96.	50.	146.
4	AL	MOBILE	0.	159.	99.	258.
4	AL	MONTGOMERY	0.	95.	44.	139.
4	AL	TUSCALOOSA	0.	30.	56.	86.
4	AL	OTHER URBAN AREAS	0.	465.	291.	756.
4	AL	TOTAL FOR STATE	0.	1239.	773.	2011.
4	FL	FT. LAUDERDALE	0.	441.	173.	614.
4	FL	GAINESVILLE	0.	40.	29.	69.
4	FL	JACKSONVILLE	0.	356.	174.	530.
4	FL	MIAMI	0.	1038.	182.	1220.
4	FL	ORLANDO	4.	215.	86.	305.
4	FL	PENSACOLA	0.	113.	54.	167.
4	FL	ST. PETERSBURG	0.	368.	127.	495.
4	FL	TALLAHASSEE	0.	54.	24.	78.
4	FL	TAMPA	0.	275.	94.	369.
4	FL	WEST PALM BEACH	0.	181.	107.	288.
4	FL	OTHER URBAN AREAS	1.	992.	337.	1330.
4	FL	TOTAL FOR STATE	6.	4075.	1385.	5465.
4	GA	ALBANY	76.	0.	0.	76.
4	GA	ATLANTA	108.	636.	429.	1173.
4	GA	AUGUSTA	73.	0.	76.	149.
4	GA	COLUMBUS	47.	61.	101.	209.
4	GA	MACON	0.	84.	44.	128.
4	GA	SAVANNAH	100.	12.	52.	164.
4	GA	OTHER URBAN AREAS	185.	363.	321.	869.
4	GA	TOTAL FOR STATE	590.	1156.	1022.	2768.
4	KY	HUNTINGTON METRO	7.	20.	20.	47.
4	KY	LEXINGTON	0.	131.	29.	160.
4	KY	LOUISVILLE	22.	545.	172.	739.
4	KY	OWENSBORO	39.	7.	6.	53.
4	KY	OTHER URBAN AREAS	47.	484.	157.	688.
4	KY	TOTAL FOR STATE	116.	1187.	384.	1687.
4	MS	BILOXI	0.	61.	60.	121.
4	MS	JACKSON	0.	127.	63.	190.
4	MS	OTHER URBAN AREAS	0.	408.	268.	676.
4	MS	TOTAL FOR STATE	0.	596.	391.	987.
4	NC	ASHEVILLE	0.	50.	22.	72.
4	NC	CHARLOTTE	0.	175.	105.	280.
4	NC	DURHAM	0.	47.	54.	101.
4	NC	FAYETTEVILLE	0.	91.	70.	161.
4	NC	GREENSBORO	0.	103.	49.	152.
4	NC	HIGHPOINT	0.	28.	66.	94.
4	NC	RALEIGH	0.	84.	68.	152.
4	NC	WILMINGTON	0.	41.	17.	58.
4	NC	WINSTON-SALEM	0.	78.	64.	142.
4	NC	OTHER URBAN AREAS	0.	618.	457.	1075.
4	NC	TOTAL FOR STATE	0.	1315.	972.	2287.
4	SC	CHARLESTON	0.	128.	100.	228.
4	SC	COLUMBIA	0.	138.	104.	242.
4	SC	GREENVILLE	0.	88.	69.	157.
4	SC	OTHER URBAN AREAS	0.	342.	264.	606.
4	SC	TOTAL FOR STATE	0.	697.	536.	1233.
4	TN	CHATTANOOGA	26.	102.	96.	224.
4	TN	KNOXVILLE	0.	107.	83.	190.
4	TN	MEMPHIS	0.	505.	159.	664.
4	TN	NASHVILLE	180.	113.	155.	448.
4	TN	OTHER URBAN AREAS	106.	423.	253.	781.
4	TN	TOTAL FOR STATE	312.	1249.	746.	2307.
4		TOTAL FOR REGION 4	1024.	11512.	6209.	18745.

TABLE III-7 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	POPULATION SERVED (1000 PERSONS) COMB	STORM	UNSEW	TOTAL
5	IL	AURORA	0.	173.	60.	233.
5	IL	BLOOMINGTON	0.	52.	17.	69.
5	IL	CHAMPAIGN	0.	91.	9.	100.
5	IL	CHICAGO	4410.	555.	753.	5718.
5	IL	DAVENPORT METRO	56.	24.	32.	112.
5	IL	DECATUR	58.	0.	42.	100.
5	IL	JOLIET	0.	110.	49.	159.
5	IL	PEORIA	117.	0.	131.	248.
5	IL	ROCKFORD	0.	157.	49.	206.
5	IL	SPRINGFIELD	33.	60.	28.	121.
5	IL	OTHER URBAN AREAS	1433.	371.	359.	2163.
5	IL	TOTAL FOR STATE	6109.	1582.	1530.	9221.
5	IN	ANDERSON	81.	0.	0.	81.
5	IN	CHICAGO METRO	453.	304.	243.	1000.
5	IN	EVANSVILLE	142.	0.	0.	142.
5	IN	FORT WAYNE	114.	56.	55.	225.
5	IN	INDIANAPOLIS	456.	157.	207.	820.
5	IN	LAFAYETTE	73.	7.	0.	80.
5	IN	MUNCIE	43.	32.	15.	90.
5	IN	SOUTH BEND	175.	0.	113.	288.
5	IN	TERRA HAUTE	0.	39.	42.	81.
5	IN	OTHER URBAN AREAS	309.	120.	136.	565.
5	IN	TOTAL FOR STATE	1845.	715.	811.	3371.
5	MI	ANN ARBOR	0.	147.	32.	179.
5	MI	BAY CITY	45.	0.	33.	78.
5	MI	DETROIT	2475.	804.	691.	3970.
5	MI	FLINT	13.	235.	82.	330.
5	MI	GRAND RAPIDS	64.	182.	106.	352.
5	MI	JACKSON	39.	0.	59.	98.
5	MI	KALAMAZOO	0.	96.	56.	152.
5	MI	LANSING	85.	81.	69.	235.
5	MI	MUSKEGON	0.	71.	35.	106.
5	MI	SAGINAW	103.	0.	45.	148.
5	MI	OTHER URBAN AREAS	469.	249.	197.	935.
5	MI	TOTAL FOR STATE	3293.	1865.	1382.	6559.
5	MN	DULUTH	31.	33.	41.	105.
5	MN	FARGO METRO	22.	4.	5.	31.
5	MN	MINNEAPOLIS	392.	830.	482.	1704.
5	MN	ROCHESTER	0.	47.	10.	57.
5	MN	OTHER URBAN AREAS	148.	304.	178.	630.
5	MN	TOTAL FOR STATE	593.	1218.	716.	2527.
5	OH	AKRON	0.	389.	154.	543.
5	OH	CANTON	20.	163.	61.	244.
5	OH	CINCINNATI	778.	43.	289.	1110.
5	OH	CLEVELAND	665.	924.	372.	1960.
5	OH	COLUMBUS	175.	437.	178.	790.
5	OH	DAYTON	0.	502.	184.	686.
5	OH	HAMILTON	35.	32.	24.	91.
5	OH	LIMA	70.	0.	0.	70.
5	OH	LORAIN	5.	119.	68.	192.
5	OH	MANSFIELD	0.	26.	52.	78.
5	OH	SPRINGFIELD	72.	11.	11.	94.
5	OH	STEUBENVILLE	45.	0.	0.	45.
5	OH	TOLEDO	208.	138.	142.	488.
5	OH	YOUNGSTOWN	172.	113.	110.	395.
5	OH	OTHER URBAN AREAS	408.	528.	299.	1235.
5	OH	TOTAL FOR STATE	2647.	3429.	1944.	8021.
5	WI	APPLETON	29.	71.	30.	130.
5	WI	DULUTH METRO	0.	18.	15.	33.
5	WI	GREEN BAY	10.	48.	71.	129.
5	WI	KENOSHA	20.	65.	0.	85.
5	WI	LA CROSSE	6.	34.	23.	63.
5	WI	MADISON	0.	151.	54.	205.
5	WI	MILWAUKEE	419.	362.	472.	1253.
5	WI	OSHKOSH	0.	55.	0.	55.
5	WI	RACINE	0.	99.	18.	117.
5	WI	OTHER URBAN AREAS	197.	368.	278.	843.
5	WI	TOTAL FOR STATE	679.	1272.	960.	2911.
5		TOTAL FOR REGION 5.	15166.	10101.	7343.	32610.

TABLE III-7 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	POPULATION SERVED (1000 PERSONS) COMB	STORM	UNSEW	TOTAL
6	AR	FORT SMITH	30.	0.	46.	76.
6	AR	LITTLE ROCK	0.	89.	134.	223.
6	AR	PINE BLUFF	0.	40.	21.	61.
6	AR	OTHER URBAN AREAS	50.	216.	336.	602.
6	AR	TOTAL FOR STATE	80.	345.	537.	962.
6	LA	BATON ROUGE	0.	172.	77.	249.
6	LA	LAFAYETTE	0.	55.	23.	78.
6	LA	LAKE CHARLES	0.	54.	34.	88.
6	LA	MONROE	0.	39.	51.	90.
6	LA	NEW ORLEANS	0.	962.	0.	962.
6	LA	SHREVEPORT	0.	140.	98.	238.
6	LA	OTHER URBAN AREAS	0.	589.	116.	705.
6	LA	TOTAL FOR STATE	0.	2012.	394.	2406.
6	NM	ALBUQUERQUE	0.	203.	94.	297.
6	NM	OTHER URBAN AREAS	0.	282.	132.	414.
6	NM	TOTAL FOR STATE	0.	485.	226.	711.
6	OK	LAWTON	0.	40.	56.	96.
6	OK	OKLAHOMA CITY	0.	404.	176.	580.
6	OK	TULSA	0.	249.	122.	371.
6	OK	OTHER URBAN AREAS	0.	458.	235.	693.
6	OK	TOTAL FOR STATE	0.	1150.	590.	1740.
6	TX	ABILENE	0.	59.	31.	90.
6	TX	AMARILLO	0.	85.	42.	127.
6	TX	AUSTIN	0.	188.	76.	264.
6	TX	BEAUMONT	38.	42.	37.	116.
6	TX	BROWNSVILLE	0.	43.	10.	53.
6	TX	BRYAN	0.	35.	16.	51.
6	TX	CORPUS CHRISTI	0.	147.	66.	213.
6	TX	DALLAS	0.	1011.	327.	1338.
6	TX	EL PASO	0.	252.	85.	337.
6	TX	FORT WORTH	0.	471.	206.	677.
6	TX	GALVESTON	40.	0.	22.	62.
6	TX	HARLINGEN	0.	9.	41.	50.
6	TX	HOUSTON	1.	1183.	494.	1678.
6	TX	LAREDO	0.	50.	20.	70.
6	TX	LUBBOCK	0.	77.	73.	150.
6	TX	MCALLEN	0.	52.	39.	91.
6	TX	MIDLAND	0.	19.	41.	60.
6	TX	ODESSA	0.	60.	22.	82.
6	TX	PORT ARTHUR	0.	50.	66.	116.
6	TX	SAN ANGELO	0.	21.	43.	64.
6	TX	SAN ANTONIO	0.	590.	182.	772.
6	TX	SHERMAN	0.	12.	43.	55.
6	TX	TEXARKANA	0.	18.	40.	58.
6	TX	TEXAS CITY	0.	50.	38.	88.
6	TX	TYLER	0.	35.	25.	60.
6	TX	WACO	0.	77.	42.	119.
6	TX	WICHITA FALL	0.	45.	53.	98.
6	TX	OTHER URBAN AREAS	23.	1350.	627.	1999.
6	TX	TOTAL FOR STATE	101.	6031.	2801.	8934.
6		TOTAL FOR REGION 6	181.	10073.	4549.	14753.

TABLE III-7 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	POPULATION SERVED (1000 PERSONS) COMB	STORM	UNSEW	TOTAL
7	IA	CEDAR RAPIDS	0.	72.	60.	132.
7	IA	DAVENPORT	3.	65.	46.	114.
7	IA	DES MOINES	118.	59.	78.	255.
7	IA	DUBUQUE	0.	51.	14.	65.
7	IA	SIOUX CITY	0.	65.	31.	96.
7	IA	WATERLOO	0.	50.	63.	113.
7	IA	OTHER URBAN AREAS	131.	392.	317.	840.
7	IA	TOTAL FOR STATE	252.	754.	609.	1615.
7	KS	KANSAS CITY METRO	76.	122.	76.	274.
7	KS	TOPEKA	45.	41.	46.	132.
7	KS	WICHITA	0.	203.	100.	303.
7	KS	OTHER URBAN AREAS	133.	402.	242.	777.
7	KS	TOTAL FOR STATE	254.	768.	463.	1485.
7	MO	COLUMBIA	0.	38.	21.	59.
7	MO	KANSAS CITY	308.	117.	403.	828.
7	MO	SPRINGFIELD	0.	74.	47.	121.
7	MO	ST. JOSEPH	77.	0.	0.	77.
7	MO	ST. LOUIS	1096.	0.	787.	1883.
7	MO	OTHER URBAN AREAS	155.	24.	131.	310.
7	MO	TOTAL FOR STATE	1635.	254.	1389.	3278.
7	NE	LINCOLN	0.	109.	44.	153.
7	NE	OMAHA	296.	75.	121.	492.
7	NE	OTHER URBAN AREAS	123.	76.	69.	268.
7	NE	TOTAL FOR STATE	419.	260.	234.	913.
7		TOTAL FOR REGION 7	2559.	2036.	2695.	7291.
8	CO	BOULDER	0.	59.	10.	69.
8	CO	COLORADO SPRINGS	0.	118.	87.	205.
8	CO	DENVER	8.	803.	236.	1047.
8	CO	PUEBLO	22.	52.	29.	103.
8	CO	OTHER URBAN AREAS	7.	227.	79.	313.
8	CO	TOTAL FOR STATE	36.	1260.	441.	1737.
8	MT	BILLINGS	0.	45.	26.	71.
8	MT	GREAT FALLS	0.	53.	18.	71.
8	MT	OTHER URBAN AREAS	0.	158.	72.	230.
8	MT	TOTAL FOR STATE	0.	256.	116.	372.
8	ND	FARGO	2.	39.	13.	54.
8	ND	OTHER URBAN AREAS	8.	158.	54.	220.
8	ND	TOTAL FOR STATE	10.	197.	67.	274.
8	SD	SIOUX FALLS	2.	46.	27.	75.
8	SD	OTHER URBAN AREAS	6.	137.	79.	222.
8	SD	TOTAL FOR STATE	8.	183.	106.	297.
8	UT	OGDEN	0.	101.	49.	150.
8	UT	PROVO	0.	70.	34.	104.
8	UT	SALT LAKE CITY	0.	335.	144.	479.
8	UT	OTHER URBAN AREAS	0.	83.	38.	121.
8	UT	TOTAL FOR STATE	0.	589.	265.	854.
8	WY	URBAN AREAS	0.	126.	75.	201.
8	WY	TOTAL FOR STATE	0.	126.	75.	201.
8		TOTAL FOR REGION 8	55.	2610.	1070.	3735.

TABLE III-7 POPULATION BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	POPULATION SERVED (1000 PERSONS) COMB	STORM	UNSEW	TOTAL
9	AK	URBAN AREAS	10.	93.	44.	147.
9	AK	TOTAL FOR STATE	10.	93.	44.	147.
9	AZ	PHOENIX	0.	620.	243.	863.
9	AZ	TUCSON	0.	193.	101.	294.
9	AZ	OTHER URBAN AREAS	0.	176.	75.	251.
9	AZ	TOTAL FOR STATE	0.	989.	419.	1408.
9	CA	BAKERSFIELD	0.	129.	47.	176.
9	CA	FRESNO	0.	195.	65.	[illegible]
9	CA	LOS ANGELES	0.	7474.	877.	8351.
9	CA	MODESTO	0.	75.	31.	106.
9	CA	OXNARD	0.	167.	78.	245.
9	CA	SACRAMENTO	70.	371.	193.	634.
9	CA	SALINAS	0.	52.	10.	62.
9	CA	SAN BERNARDINO	0.	415.	170.	585.
9	CA	SAN DIEGO	0.	[illegible]	[illegible]	[illegible]
9	CA	SAN FRANCISCO	1410.	[illegible]	[illegible]	[illegible]
9	CA	SAN JOSE	0.	[illegible]	[illegible]	[illegible]
9	CA	SANTA BARBARA	0.	99.	31.	130.
9	CA	SANTA ROSA	0.	26.	49.	75.
9	CA	SEASIDE	0.	85.	8.	93.
9	CA	SIMI VALLEY	0.	32.	25.	57.
9	CA	STOCKTON	0.	120.	40.	160.
9	CA	OTHER URBAN AREAS	183.	1464.	328.	[illegible]
9	CA	TOTAL FOR STATE	1663.	13493.	2986.	18142.
9	HI	HONOLULU	0.	346.	96.	442.
9	HI	OTHER URBAN AREAS	0.	153.	43.	196.
9	HI	TOTAL FOR STATE	0.	499.	139.	638.
9	NV	LAS VEGAS	0.	157.	80.	237.
9	NV	RENO	35.	27.	38.	100.
9	NV	OTHER URBAN AREAS	6.	32.	21.	59.
9	NV	TOTAL FOR STATE	41.	217.	139.	396.
9		TOTAL FOR REGION 9	1713.	15291.	3727.	20731.
10	ID	BOISE	0.	51.	34.	85.
10	ID	OTHER URBAN AREAS	0.	181.	121.	302.
10	ID	TOTAL FOR STATE	0.	232.	155.	387.
10	OR	EUGENE	6.	85.	47.	139.
10	OR	PORTLAND	316.	291.	219.	825.
10	OR	SALEM	0.	56.	37.	93.
10	OR	OTHER URBAN AREAS	105.	142.	99.	346.
10	OR	TOTAL FOR STATE	427.	574.	402.	1403.
10	WA	SEATTLE	483.	417.	338.	1238.
10	WA	SPOKANE	165.	0.	65.	230.
10	WA	TACOMA	9.	219.	106.	334.
10	WA	OTHER URBAN AREAS	246.	237.	191.	675.
10	WA	TOTAL FOR STATE	903.	871.	701.	2475.
10		TOTAL FOR REGION 10	1330.	1677.	1258.	4265.
		TOTAL FOR THE U.S.	37606.	77853.	33906.	149366.

TABLE XII-8 DEVELOPED POPULATION DENSITY BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	DEVELOPED POPULATION DENSITY (PERSONS/ACRE) COMP	STORM	UNSEW	AVER
1	CT	BRIDGEPORT	12.38	12.38	4.77	[illegible]
1	CT	BRISTOL	0.0	11.81	3.65	[illegible]
1	CT	DANBURY	0.0	11.07	3.98	[illegible]
1	CT	HARTFORD	13.25	12.25	4.89	[illegible]
1	CT	MERIDEN	0.0	12.55	4.87	[illegible]
1	CT	NEW BRITAIN	0.0	11.50	5.59	[illegible]
1	CT	NEW HAVEN	11.98	11.98	5.07	[illegible]
1	CT	NORWALK	10.67	4.48	4.43	[illegible]
1	CT	STAMFORD	0.0	12.00	4.98	[illegible]
1	CT	WATERBURY	12.45	12.45	4.69	[illegible]
1	CT	OTHER URBAN AREAS	13.47	11.88	4.63	8.39
1	CT	AVE. FOR STATE	13.47	11.88	4.63	8.39
1	ME	LEWISTON	10.28	0.0	3.30	6.66
1	ME	PORTLAND	7.48	0.0	7.48	7.48
1	ME	OTHER URBAN AREAS	8.36	0.0	5.12	7.15
1	ME	AVE. FOR STATE	8.36	0.0	5.12	7.15
1	MA	BOSTON	15.81	15.81	3.63	9.34
1	MA	BROCKTON	[illegible]	12.39	4.77	8.35
1	MA	FALL RIVER	13.71	12.71	4.68	8.76
1	MA	FITCHBURG	12.26	12.24	3.93	[illegible]
1	MA	LAWRENCE	10.58	0.0	5.83	[illegible]
1	MA	LOWELL	13.92	13.97	4.06	8.49
1	MA	NEW BEDFORD	11.26	11.26	5.54	9.49
1	MA	PITTSFIELD	0.0	12.69	3.84	7.07
1	MA	SPRINGFIELD	7.73	0.0	7.73	7.73
1	MA	WORCESTER	16.29	11.03	5.16	8.68
1	MA	OTHER URBAN AREAS	11.30	14.98	4.55	8.93
1	MA	AVE. FOR STATE	11.30	14.98	4.55	8.93
1	NH	MANCHESTER	10.14	0.0	4.91	7.99
1	NH	NASHUA	7.39	0.0	7.39	7.39
1	NH	OTHER URBAN AREAS	9.02	0.0	5.92	7.75
1	NH	AVE. FOR STATE	9.02	0.0	5.92	7.75
1	RI	PROVIDENCE	15.85	11.60	4.20	8.79
1	RI	OTHER URBAN AREAS	15.85	11.60	4.20	8.79
1	RI	AVE. FOR STATE	15.85	11.60	4.20	8.79
1	VT	URBAN AREAS	8.75	0.0	7.73	8.19
1	VT	AVE. FOR STATE	8.75	0.0	7.73	8.19
1		AVE. FOR REGION 1	11.27	13.71	4.67	8.58
2	NJ	ATLANTIC CITY	0.0	13.91	3.64	7.58
2	NJ	NEW YORK CITY METRO	32.84	15.19	3.39	[illegible]
2	NJ	PHILADELPHIA METRO	9.90	0.0	1.76	[illegible]
2	NJ	TRENTON	0.0	11.24	5.56	[illegible]
2	NJ	VINELAND	0.0	10.70	4.37	6.59
2	NJ	AVE. FOR STATE	15.27	14.83	3.45	8.37
2	NY	ALBANY	14.06	14.06	4.07	8.75
2	NY	BINGHAMPTON	9.55	0.0	5.59	8.74
2	NY	BUFFALO	16.76	9.12	4.84	10.71
2	NY	NEW YORK CITY	62.46	27.87	0.0	41.28
2	NY	ROCHESTER	16.83	16.83	3.53	9.67
2	NY	SYRACUSE	12.06	12.06	5.11	[illegible]
2	NY	UTICA	11.91	11.91	5.00	[illegible]
2	NY	OTHER URBAN AREAS	39.10	22.27	4.38	24.68
2	NY	AVE. FOR STATE	39.10	22.27	4.38	24.68
2		AVE. FOR REGION 2	36.78	18.18	3.68	15.77

TABLE III-8 DEVELOPED POPULATION DENSITY BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	DEVELOPED POPULATION DENSITY (PERSONS/ACRE) COMB	STORM	UNSEW	AVER
3	DE	WILMINGTON	12.23	12.23	4.98	8.91
3	DE	OTHER URBAN AREAS	12.23	12.23	4.98	8.91
3	DE	AVE. FOR STATE	12.23	12.23	4.98	8.91
3	DC	WASHINGTON,D.C.	31.40	14.24	0.0	20.02
3	DC	AVE. FOR STATE	31.40	14.28	0.0	20.02
3	MD	BALTIMORE	0.0	13.27	4.84	10.74
3	MD	WASHINGTON DC METRO	0.0	13.72	4.41	9.49
3	MD	OTHER URBAN AREAS	0.0	13.36	4.70	10.42
3	MD	AVE. FOR STATE	0.0	13.36	4.70	10.42
3	PA	ALLENTOWN	13.48	13.48	4.44	9.22
3	PA	ALTOONA	11.29	11.29	5.53	9.66
3	PA	ERIE	11.64	11.06	5.54	9.53
3	PA	HARRISBURG	14.03	14.03	4.06	8.62
3	PA	JOHNSTOWN	9.98	9.98	6.54	8.96
3	PA	LANCASTER	11.12	11.12	5.64	8.53
3	PA	PHILADELPHIA	14.59	12.64	5.10	11.11
3	PA	PITTSBURGH	21.14	21.14	2.30	8.63
3	PA	READING	0.0	11.25	5.55	9.65
3	PA	SCRANTON	8.67	0.0	5.84	7.66
3	PA	WILKES-BARRE	12.02	12.02	4.98	8.23
3	PA	YORK	0.0	10.62	6.00	8.86
3	PA	OTHER URBAN AREAS	15.17	13.43	3.76	9.80
3	PA	AVE. FOR STATE	15.17	13.43	3.74	9.80
3	VA	LYNCHBERG	6.83	0.0	0.0	6.83
3	VA	NEWPORT NEWS	0.0	12.75	4.20	7.47
3	VA	NORFOLK	0.0	14.53	3.51	7.80
3	VA	PETERSBURG	0.0	14.70	3.51	7.96
3	VA	RICHMOND	12.61	12.61	4.71	8.41
3	VA	ROANOKE	11.23	11.23	5.56	7.94
3	VA	WASHINGTON DC METRO	16.00	14.12	0.0	14.16
3	VA	OTHER URBAN AREAS	10.63	13.89	4.10	9.70
3	VA	AVE. FOR STATE	10.63	13.89	4.10	9.70
3	WV	CHARLESTON	12.34	12.34	4.71	8.10
3	WV	HUNTINGTON	8.18	0.0	0.0	8.18
3	WV	STEUBENVILLE METRO	6.06	0.0	0.0	6.06
3	WV	WHEELING	10.02	10.02	6.54	8.85
3	WV	OTHER URBAN AREAS	8.94	12.04	5.16	8.01
3	WV	AVE. FOR STATE	8.94	12.04	5.16	8.01
3		AVE. FOR REGION 3	13.63	13.49	4.08	10.01

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TABLE III-8 DEVELOPED POPULATION DENSITY BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	DEVELOPED POPULATION DENSITY (PERSONS/ACRE)			
			COMB	STORM	UNSEW	AVER
4	AL	BIRMINGHAM	0.0	11.52	5.31	8.03
4	AL	GADSDEN	0.0	12.13	3.96	6.90
4	AL	HUNTSVILLE	0.0	12.16	3.71	6.86
4	AL	MOBILE	0.0	12.22	4.31	7.16
4	AL	MONTGOMERY	0.0	12.12	4.93	8.27
4	AL	TUSCALOOSA	0.0	9.84	6.72	7.58
4	AL	OTHER URBAN AREAS	0.0	11.78	4.84	7.61
4	AL	AVE. FOR STATE	0.0	11.78	4.84	7.61
4	FL	FT.LAUDERDALE	0.0	13.08	4.42	8.43
4	FL	GAINESVILLE	0.0	11.13	5.65	7.94
4	FL	JACKSONVILLE	0.0	12.20	3.87	7.14
4	FL	MIAMI	0.0	12.78	4.90	10.31
4	FL	ORLANDO	14.20	14.20	3.69	7.87
4	FL	PENSACOLA	0.0	12.55	4.61	8.08
4	FL	ST.PETERSBURG	0.0	14.03	4.05	8.61
4	FL	TALLAHASSEE	0.0	12.93	4.41	8.15
4	FL	TAMPA	0.0	14.86	3.65	8.35
4	FL	WEST PALM BEACH	0.0	12.17	4.73	7.60
4	FL	OTHER URBAN AREAS	14.20	13.08	4.26	8.58
4	FL	AVE. FOR STATE	14.20	13.08	4.26	8.58
4	GA	ALBANY	6.33	0.0	0.0	6.33
4	GA	ATLANTA	11.44	11.40	5.55	8.20
4	GA	AUGUSTA	8.12	0.0	8.12	8.12
4	GA	COLUMBUS	11.06	11.06	5.69	7.56
4	GA	MACON	0.0	12.04	4.93	8.06
4	GA	SAVANNAH	15.38	4.99	4.59	8.11
4	GA	OTHER URBAN AREAS	9.81	11.25	5.62	8.03
4	GA	AVE. FOR STATE	9.81	11.25	5.62	8.03
4	KY	HUNTINGTON METRO	11.03	11.03	5.75	7.96
4	KY	LEXINGTON	0.0	11.49	5.45	9.55
4	KY	LOUISVILLE	14.22	14.22	4.12	9.05
4	KY	OWENSBORO	11.33	11.23	5.58	9.99
4	KY	OTHER URBAN AREAS	12.03	13.48	4.40	9.12
4	KY	AVE. FOR STATE	12.03	13.48	4.40	9.12
4	MS	BILOXI	0.0	11.00	5.66	7.48
4	MS	JACKSON	0.0	11.87	5.02	8.18
4	MS	OTHER URBAN AREAS	0.0	11.57	5.32	7.90
4	MS	AVE. FOR STATE	0.0	11.57	5.32	7.90
4	NC	ASHEVILLE	0.0	13.71	3.97	7.49
4	NC	CHARLOTTE	0.0	11.05	5.72	8.19
4	NC	DURHAM	0.0	10.17	6.63	7.91
4	NC	FAYETTEVILLE	0.0	11.18	5.59	7.77
4	NC	GREENSBORO	0.0	12.52	4.61	8.04
4	NC	HIGHPOINT	0.0	9.55	6.74	7.81
4	NC	RALEIGH	0.0	12.04	5.33	7.71
4	NC	WILMINGTON	0.0	14.05	3.57	7.58
4	NC	WINSTON-SALEM	0.0	11.15	5.60	7.72
4	NC	OTHER URBAN AREAS	0.0	11.56	5.46	7.84
4	NC	AVE. FOR STATE	0.0	11.56	5.46	7.84
4	SC	CHARLESTON	0.0	11.01	5.76	7.86
4	SC	COLUMBIA	0.0	11.44	5.61	7.91
4	SC	GREENVILLE	0.0	11.18	5.59	7.78
4	SC	OTHER URBAN AREAS	0.0	11.27	5.66	7.86
4	SC	AVE. FOR STATE	0.0	11.27	5.66	7.86
4	TN	CHATTANOOGA	11.61	11.61	5.10	7.50
4	TN	KNOXVILLE	0.0	11.39	5.52	7.78
4	TN	MEMPHIS	0.0	14.14	4.11	8.97
4	TN	NASHVILLE	12.24	9.81	4.07	6.96
4	TN	OTHER URBAN AREAS	12.16	12.64	4.45	7.90
4	TN	AVE. FOR STATE	12.16	12.64	4.45	7.90
4		AVE. FOR REGION 4	10.68	12.33	4.90	8.16

TABLE III-8 DEVELOPED POPULATION DENSITY BY TYPE OF SEWERAGE SYSTEM

EPA RGN	STATE ID	URBANIZED AREA	DEVELOPED POPULATION DENSITY (PERSONS/ACRE) COMB	STORM	UNSEW	AVER
5	IL	AURORA	0.0	13.98	4.06	8.56
5	IL	BLOOMINGTON	0.0	13.38	4.43	8.98
5	IL	CHAMPAIGN	0.0	12.73	5.12	11.25
5	IL	CHICAGO	21.55	6.68	4.38	11.56
5	IL	DAVENPORT METRO	9.84	9.84	6.79	8.71
5	IL	DECATUR	8.28	0.0	8.28	8.28
5	IL	JOLIET	0.0	12.56	4.68	8.37
5	IL	PEORIA	7.87	0.0	7.87	7.87
5	IL	ROCKFORD	0.0	13.28	4.07	8.91
5	IL	SPRINGFIELD	11.59	11.28	5.51	9.04
5	IL	OTHER URBAN AREAS	19.91	7.24	4.75	10.88
5	IL	AVE. FOR STATE	19.91	7.24	4.75	10.88
5	IN	ANDERSON	4.05	0.0	0.0	4.05
5	IN	CHICAGO METRO	14.01	14.01	4.14	8.88
5	IN	EVANSVILLE	8.99	0.0	0.0	8.99
5	IN	FORT WAYNE	14.16	14.16	4.06	8.79
5	IN	INDIANAPOLIS	13.40	13.40	3.47	7.72
5	IN	LAFAYETTE	14.50	8.08	0.0	9.75
5	IN	MUNCIE	9.91	8.91	6.54	9.14
5	IN	SOUTH BEND	8.64	0.0	7.90	8.33
5	IN	TERRA HAUTE	0.0	9.98	6.64	8.08
5	IN	OTHER URBAN AREAS	10.99	12.48	4.34	8.19
5	IN	AVE. FOR STATE	10.99	12.48	4.34	8.19
5	MI	ANN ARBOR	0.0	11.26	5.54	9.53
5	MI	BAY CITY	8.53	0.0	8.53	8.53
5	MI	DETROIT	14.69	11.93	4.38	10.18
5	MI	FLINT	12.01	12.01	5.08	8.47
5	MI	GRAND RAPIDS	13.43	13.43	4.09	7.97
5	MI	JACKSON	8.86	0.0	6.92	7.74
5	MI	KALAMAZOO	0.0	12.23	4.67	7.66
5	MI	LANSING	11.07	11.82	5.14	8.68
5	MI	MUSKEGON	0.0	12.94	4.18	7.82
5	MI	SAGINAW	8.90	0.0	8.90	8.98
5	MI	OTHER URBAN AREAS	14.08	12.08	4.68	9.57
5	MI	AVE. FOR STATE	14.08	12.08	4.68	9.57
5	MN	DULUTH	12.10	12.10	4.33	7.11
5	MN	FARGO METRO	8.82	8.82	6.54	9.10
5	MN	MINNEAPOLIS	12.57	12.57	4.09	7.82
5	MN	ROCHESTER	0.0	10.51	6.01	9.34
5	MN	OTHER URBAN AREAS	12.37	12.41	4.14	7.97
5	MN	AVE. FOR STATE	12.37	12.41	4.10	7.97
5	OH	AKRON	0.0	13.03	4.09	8.20
5	OH	CANTON	13.56	13.93	4.06	8.70
5	OH	CINCINNATI	10.59	10.59	4.03	8.85
5	OH	CLEVELAND	18.97	18.97	3.75	8.87
5	OH	COLUMBUS	15.78	15.78	3.56	8.89
5	OH	DAYTON	0.0	13.22	4.40	8.60
5	OH	HAMILTON	14.73	14.73	3.51	7.95
5	OH	LIMA	6.93	0.0	0.0	6.93
5	OH	LORAIN	50.00	13.30	4.20	7.61
5	OH	MANSFIELD	0.0	10.75	4.73	7.49
5	OH	SPRINGFIELD	9.84	9.84	6.56	9.30
5	OH	STEUBENVILLE	10.71	0.0	0.0	9.20
5	OH	TOLEDO	12.84	11.91	4.77	8.47
5	OH	YOUNGSTOWN	12.88	12.08	4.77	8.60
5	OH	OTHER URBAN AREAS	12.53	14.03	3.98	8.55
5	OH	AVE. FOR STATE	12.53	14.43	3.99	8.55
5	WI	APPLETON	14.33	14.33	4.07	9.05
5	WI	DULUTH METRO	0.0	10.87	4.40	6.55
5	WI	GREEN BAY	10.73	10.73	5.76	7.87
5	WI	KENOSHA	13.93	9.51	0.0	10.26
5	WI	LA CROSSE	11.16	11.16	5.62	8.17
5	WI	MADISON	0.0	13.58	4.18	8.51
5	WI	MILWAUKEE	23.57	6.47	6.04	8.28
5	WI	OSHKOSH	0.0	9.79	0.0	9.79
5	WI	RACINE	0.0	11.20	5.56	9.70
5	WI	OTHER URBAN AREAS	21.37	8.81	5.64	8.41
5	WI	AVE. FOR STATE	21.37	8.81	5.65	8.41
5		AVE. FOR REGION 5	15.17	11.08	4.49	9.19

TABLE III-8 DEVELOPED POPULATION DENSITY BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	DEVELOPED POPULATION DENSITY (PERSONS/ACRE)			
			COMB	STORM	UNSEW	AVER
6	AR	FORT SMITH	6.93	0.0	6.93	6.93
6	AR	LITTLE ROCK	0.0	11.86	6.47	7.91
6	AR	PINE BLUFF	0.0	10.70	6.01	8.44
6	AR	OTHER URBAN AREAS	6.93	11.47	6.52	7.76
6	AR	AVE. FOR STATE	6.93	11.47	6.52	7.76
6	LA	BATON ROUGE	0.0	12.05	5.08	8.46
6	LA	LAFAYETTE	0.0	10.65	6.00	8.65
6	LA	LAKE CHARLES	0.0	11.12	5.66	8.13
6	LA	MONROE	0.0	10.36	6.57	7.81
6	LA	NEW ORLEANS	0.0	18.79	0.0	18.79
6	LA	SHREVEPORT	0.0	11.08	5.73	8.08
6	LA	OTHER URBAN AREAS	0.0	15.47	5.68	12.06
6	LA	AVE. FOR STATE	0.0	15.47	5.68	12.06
6	NM	ALBUQU	0.0	12.66	4.62	8.15
6	NM	OTHER URBAN AREAS	0.0	12.66	4.62	8.15
6	NM	AVE. FOR STATE	0.0	12.66	4.62	8.15
6	OK	LAWTON	0.0	10.09	6.66	7.75
6	OK	OKLAHOMA CITY	0.0	13.67	3.55	7.32
6	OK	TULSA	0.0	12.90	4.19	7.64
6	OK	OTHER URBAN AREAS	0.0	13.12	4.06	7.47
6	OK	AVE. FOR STATE	0.0	13.12	4.06	7.47
6	TX	ABILENE	0.0	12.23	3.74	6.83
6	TX	AMARILLO	0.0	13.03	4.15	7.66
6	TX	AUSTIN	0.0	11.81	5.16	8.60
6	TX	BEAUMONT	13.37	13.87	3.61	7.17
6	TX	BROWNSVILLE	0.0	6.93	6.54	9.07
6	TX	BRYAN	0.0	13.26	3.81	7.17
6	TX	CORPUS CHRISTI	0.0	13.50	3.57	7.25
6	TX	DALLAS	0.0	13.63	3.19	7.57
6	TX	EL PASO	0.0	13.83	3.47	6.37
6	TX	FORT WORTH	0.0	13.67	3.55	7.32
6	TX	GALVESTON	36.36	0.0	5.54	8.28
6	TX	HARLINGEN	0.0	8.10	6.91	7.11
6	TX	HOUSTON	25.00	11.10	5.65	8.65
6	TX	LAREDO	0.0	10.65	6.00	8.71
6	TX	LUBBOCK	0.0	11.08	5.65	7.53
6	TX	MCALLEN	0.0	8.99	6.76	8.30
6	TX	MIDLAND	0.0	9.70	6.74	7.97
6	TX	ODESSA	0.0	10.63	6.00	6.81
6	TX	PORT ARTHUR	0.0	10.64	5.79	7.21
6	TX	SAN ANGELO	0.0	9.71	6.74	7.47
6	TX	SAN ANTONIO	0.0	16.19	4.11	9.00
6	TX	SHERMAN	0.0	8.70	6.66	7.20
6	TX	TEXARKANA	0.0	9.69	6.74	7.66
6	TX	TEXAS CITY	0.0	11.38	4.19	9.71
6	TX	TYLER	0.0	11.13	5.65	7.98
6	TX	WACO	0.0	12.39	3.90	8.98
6	TX	WICHITA FALL	0.0	10.36	6.63	7.89
6	TX	OTHER URBAN AREAS	19.78	12.33	4.48	7.98
6	TX	AVE. FOR STATE	19.78	12.33	4.48	7.98
6		AVE. FOR REGION 6	10.87	12.93	4.68	8.37

TABLE III-8 DEVELOPED POPULATION DENSITY BY TYPE OF SEWERAGE SYSTEM

EPA RGS	STATE ID	URBANIZED AREA	DEVELOPED POPULATION DENSITY (PERSONS/ACRE) COMB	STORM	UNSEW	AVER
7	IA	CEDAR RAPIDS	0.0	11.15	5.60	7.70
7	IA	DAVENPORT	11.89	11.48	4.38	7.02
7	IA	DES MOINES	24.42	5.84	4.29	7.98
7	IA	DUBUQUE	0.0	8.84	6.24	[illegible]
7	IA	SIOUX CITY	0.0	13.10	5.76	7.22
7	IA	WATERLOO	0.0	10.71	5.76	7.27
7	IA	OTHER URBAN AREAS	28.38	9.84	4.61	7.61
7	IA	AVE. FOR STATE	28.38	9.88	4.81	7.61
7	KS	KANSAS CITY METRO	11.82	11.82	5.16	8.72
7	KS	TOPEKA	12.12	[illegible]	4.41	8.04
7	KS	WICHITA	0.0	11.80	[illegible]	8.41
7	KS	OTHER URBAN AREAS	11.93	11.50	5.29	8.45
7	KS	AVE. FOR STATE	11.93	11.50	5.29	8.45
7	MO	COLUMBIA	0.0	12.62	3.85	7.05
7	MO	KANSAS CITY	14.67	[illegible]	5.76	7.81
7	MO	SPRINGFIELD	0.0	[illegible]	4.71	[illegible]
7	MO	ST. JOSEPH	[illegible]	0.0	0.0	[illegible]
7	MO	ST. LOUIS	[illegible]	0.0	[illegible]	[illegible]
7	MO	OTHER URBAN AREAS	10.00	8.52	7.49	8.65
7	MO	AVE. FOR STATE	10.00	8.52	7.49	8.65
7	NE	LINCOLN	0.0	12.93	4.59	8.48
7	NE	OMAHA	14.17	[illegible]	4.08	8.79
7	NE	OTHER URBAN AREAS	14.17	13.41	4.19	8.71
7	NE	AVE. FOR STATE	14.17	13.41	4.19	8.71
7		AVE. FOR REGION 7	11.46	10.57	5.92	8.37
8	CO	BOULDER	0.0	12.91	4.93	10.55
8	CO	COLORADO SPRINGS	0.0	[illegible]	5.58	[illegible]
8	CO	DENVER	[illegible]	[illegible]	4.30	[illegible]
8	CO	PUEBLO	[illegible]	[illegible]	[illegible]	[illegible]
8	CO	OTHER URBAN AREAS	19.93	12.88	4.66	8.93
8	CO	AVE. FOR STATE	19.93	12.88	4.66	8.93
8	MT	BILLINGS	0.0	11.16	5.62	8.17
8	MT	GREAT FALLS	0.0	10.12	5.86	[illegible]
8	MT	OTHER URBAN AREAS	0.0	10.57	5.86	8.46
8	MT	AVE. FOR STATE	0.0	10.57	5.86	8.46
8	ND	FARGO	10.67	10.67	6.18	9.06
8	ND	OTHER URBAN AREAS	10.67	10.67	6.18	9.06
8	ND	AVE. FOR STATE	10.67	10.67	6.18	9.06
8	SD	SIOUX FALLS	12.23	12.23	5.28	8.32
8	SD	OTHER URBAN AREAS	12.23	12.23	5.28	8.32
8	SD	AVE. FOR STATE	12.23	12.23	5.28	8.32
8	UT	OGDEN	0.0	12.50	[illegible]	[illegible]
8	UT	PROVO	0.0	[illegible]	[illegible]	[illegible]
8	UT	SALT LAKE CITY	0.0	[illegible]	[illegible]	[illegible]
8	UT	OTHER URBAN AREAS	0.0	12.79	4.37	7.98
8	UT	AVE. FOR STATE	0.0	12.79	4.37	7.98
8	WY	URBAN AREAS	0.0	11.16	5.62	8.16
8	WY	AVE. FOR STATE	0.0	11.16	5.62	8.16
8		AVE. FOR REGION 8.	15.90	12.24	4.89	8.56

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TABLE III-8 DEVELOPED POPULATION DENSITY BY TYPE OF SEWERAGE SYSTEM

EPA REG	STATE ID	URBANIZED AREA	DEVELOPED POPULATION DENSITY (PERSONS/ACRE) COMB	STORM	UNSEW	AVER
9	AK	URBAN AREAS	13.75	13.75	3.66	7.50
9	AK	AVE. FOR STATE	13.75	13.75	3.66	7.50
9	AZ	PHOENIX	0.0	12.51	3.97	7.79
9	AZ	TUCSON	0.0	11.51	5.48	8.38
9	AZ	OTHER URBAN AREAS	0.0	12.26	4.32	7.92
9	AZ	AVE. FOR STATE	0.0	12.26	4.32	7.92
9	CA	BAKERSFIELD	0.0	13.23	4.40	8.62
9	CA	FRESNO	0.0	11.58	5.17	8.66
9	CA	LOS ANGELES	0.0	12.71	5.09	10.98
9	CA	MODESTO	0.0	11.11	5.64	8.95
9	CA	OXNARD	0.0	13.18	4.12	7.76
9	CA	SACRAMENTO	12.49	12.49	4.54	8.14
9	CA	SALINAS	0.0	11.25	5.55	9.69
9	CA	SAN BERNARDINO	0.0	14.05	3.50	7.48
9	CA	SAN DIEGO	0.0	13.13	4.46	8.68
9	CA	SAN FRANCISCO	26.04	13.54	2.94	9.86
9	CA	SAN JOSE	0.0	14.24	4.15	9.24
9	CA	SANTA BARBARA	0.0	11.29	5.31	9.05
9	CA	SANTA ROSA	0.0	9.87	6.71	7.56
9	CA	SEASIDE	0.0	9.80	6.58	9.82
9	CA	SIMI VALLEY	0.0	11.06	5.70	7.88
9	CA	STOCKTON	0.0	11.30	5.50	8.94
9	CA	OTHER URBAN AREAS	24.79	12.85	4.21	9.93
9	CA	AVE. FOR STATE	24.79	12.85	4.21	9.93
9	HI	HONOLULU	0.0	13.55	4.46	9.39
9	HI	OTHER URBAN AREAS	0.0	13.55	4.46	9.39
9	HI	AVE. FOR STATE	0.0	13.55	4.46	9.39
9	NV	LAS VEGAS	0.0	12.90	4.16	7.54
9	NV	RENO	14.38	10.60	5.25	8.18
9	NV	OTHER URBAN AREAS	14.38	12.50	4.46	7.72
9	NV	AVE. FOR STATE	14.38	12.50	4.46	7.72
9		AVE. FOR REGION 9	24.26	12.83	4.23	9.65
10	ID	BOISE	0.0	10.58	6.52	8.47
10	ID	OTHER URBAN AREAS	0.0	10.58	6.52	8.47
10	ID	AVE. FOR STATE	0.0	10.58	6.52	8.47
10	OR	EUGENE	12.05	12.05	4.93	8.08
10	OR	PORTLAND	13.06	13.06	4.44	8.62
10	OR	SALEM	0.0	11.11	5.67	8.06
10	OR	OTHER URBAN AREAS	13.04	12.57	4.64	8.50
10	OR	AVE. FOR STATE	13.04	12.57	4.64	8.50
10	WA	SEATTLE	12.74	12.74	4.54	8.53
10	WA	SPOKANE	8.48	0.0	8.48	8.48
10	WA	TACOMA	12.47	12.47	4.67	8.12
10	WA	OTHER URBAN AREAS	11.31	12.65	4.86	8.45
10	WA	AVE. FOR STATE	11.31	12.65	4.86	8.45
10		AVE. FOR REGION 10	11.82	12.29	4.94	8.46
		AVERAGE FOR THE U.S.	16.73	13.00	4.59	9.56

TABLE III-9 VALUES OF COEFFICIENTS

EPA REG	STATE ID	URBANIZED AREA	VALUES OF COEFFICIENTS a	a'	b	x_1	x_2	Z
1	CT	BRIDGEPORT	57.7	75.5	-0.77	2.00	24.3	0.479
1	CT	BRISTOL	91.7	116.1	-1.06	2.00	15.4	0.596
1	CT	DANBURY	57.4	82.2	-1.06	2.00	9.9	0.724
1	CT	HARTFORD	94.3	112.7	-0.85	2.14	32.1	0.390
1	CT	MERIDEN	65.1	89.9	-1.06	2.00	11.2	0.693
1	CT	NEW BRITAIN	43.7	57.3	-0.61	2.00	34.5	0.410
1	CT	NEW HAVEN	55.6	71.2	-0.70	2.00	31.1	0.427
1	CT	NORWALK	66.5	86.3	-0.85	2.00	21.4	0.508
1	CT	STAMFORD	48.1	65.2	-0.72	2.00	23.0	0.496
1	CT	WATERBURY	57.6	76.1	-0.79	2.00	22.4	0.490
1	ME	LEWISTON	30.3	52.4	-0.91	2.00	10.8	0.776
1	ME	PORTLAND	92.9	119.7	-1.06	2.29	28.7	0.605
1	MA	BOSTON	231.8	256.9	-1.11	2.65	31.8	0.346
1	MA	BROCKTON	58.5	76.2	-0.77	2.00	24.7	0.474
1	MA	FALL RIVER	71.2	88.6	-0.79	2.00	29.3	0.428
1	MA	FITCHBURG	60.3	85.1	-1.06	2.00	10.4	0.712
1	MA	LAWRENCE	30.6	45.5	-0.61	2.00	22.3	0.531
1	MA	LOWELL	98.1	118.8	-0.93	2.00	24.4	0.457
1	MA	NEW BEDFORD	51.3	64.0	-0.61	2.00	44.8	0.351
1	MA	PITTSFIELD	67.5	92.3	-1.06	2.00	11.6	0.684
1	MA	SPRINGFIELD	32.3	48.5	-0.66	2.00	31.6	0.563
1	MA	WORCESTER	47.4	63.1	-0.68	2.00	27.1	0.458
1	NH	MANCHESTER	126.2	152.7	-1.05	2.33	28.0	0.524
1	NH	NASHUA	12.1	23.5	-0.41	2.00	22.4	0.621
1	RI	PROVIDENCE	108.6	129.9	-0.92	2.29	28.2	0.421
1	VT	URBAN AREAS	130.9	154.5	-1.08	2.00	22.9	0.495
2	NJ	ATLANTIC CITY	94.3	118.6	-1.06	2.00	15.8	0.588
2	NJ	NEW YORK CITY METRO	147.3	170.9	-1.11	2.00	21.1	0.478
2	NJ	PHILADELPHIA METRO	53.7	66.0	-0.61	2.00	64.7	0.335
2	NJ	TRENTON	54.9	67.1	-0.61	2.00	50.0	0.326
2	NJ	VINELAND	41.0	65.5	-1.06	2.00	7.2	0.798
2	NY	ALBANY	108.3	128.7	-0.93	2.05	26.9	0.425
2	NY	BINGHAMPTON	107.2	127.3	-0.93	2.00	45.7	0.426
2	NY	BUFFALO	113.7	127.6	-0.79	2.00	51.6	0.260
2	NY	NEW YORK CITY	899.0	899.2	-0.92	2.00	99.9	0.001
2	NY	ROCHESTER	203.5	223.7	-1.08	2.00	30.7	0.335
2	NY	SYRACUSE	67.0	81.4	-0.70	2.00	40.5	0.353
2	NY	UTICA	43.7	61.1	-0.72	2.00	20.1	0.529

TABLE III-9 VALUES OF COEFFICIENTS

EPA REG	STATE ID	URBANIZED AREA	VALUES OF COEFFICIENTS a	a'	b	x_1	x_2	Z
3	DE	WILMINGTON	59.5	74.9	-0.71	1.88	32.0	0.408
3	DC	WASHINGTON,D.C.	237.5	241.2	-0.75	1.83	96.2	0.038
3	MD	BALTIMORE	114.2	128.1	-0.79	2.00	51.9	0.258
3	MD	WASHINGTON DC METRO	107.0	124.3	-0.86	2.00	35.4	0.351
3	PA	ALLENTOWN	96.4	114.1	-0.85	2.00	32.9	0.377
3	PA	ALTOONA	54.1	66.6	-0.62	2.00	47.6	0.337
3	PA	ERIE	51.8	64.4	-0.61	2.00	45.5	0.348
3	PA	HARRISBURG	102.7	123.1	-0.93	2.00	25.6	0.440
3	PA	JOHNSTOWN	23.2	32.9	-0.41	2.00	42.2	0.402
3	PA	LANCASTER	35.6	49.1	-0.58	2.00	29.0	0.451
3	PA	PHILADELPHIA	106.0	118.5	-0.75	2.00	60.3	0.236
3	PA	PITTSBURGH	374.6	398.2	-1.47	2.00	18.8	0.439
3	PA	READING	53.4	65.8	-0.61	2.00	47.7	0.337
3	PA	SCRANTON	11.0	20.6	-0.34	2.00	27.3	0.575
3	PA	WILKES-BARRE	48.9	65.9	-0.72	2.00	23.6	0.490
3	PA	YORK	31.6	43.2	-0.51	2.00	36.3	0.414
3	VA	LYNCHBERG	13.0	22.6	-0.41	2.00	43.9	0.561
3	VA	NEWPORT NEWS	61.4	83.7	-0.93	2.00	15.0	0.608
3	VA	NORFOLK	112.6	137.4	-1.09	2.00	17.4	0.552
3	VA	PETERSBURG	118.9	142.9	-1.08	2.00	18.7	0.528
3	VA	RICHMOND	58.9	76.4	-0.77	1.84	24.9	0.467
3	VA	ROANOKE	30.6	45.5	-0.61	2.00	19.6	0.532
3	VA	WASHINGTON DC METRO	178.6	167.4	-0.79	2.00	88.0	0.120
3	WV	CHARLESTON	56.8	75.6	-0.79	2.07	21.8	0.508
3	WV	HUNTINGTON	73.4	87.6	-0.79	2.00	63.7	0.363
3	WV	STEUBENVILLE METRO	79.9	100.5	-1.11	2.00	38.6	0.614
3	WV	WHEELING	22.5	32.2	-0.41	2.00	39.0	0.414

TABLE III-9 VALUES OF COEFFICIENTS

EPA REG	STATE ID	URBANIZED AREA	VALUES OF COEFFICIENTS					
			a	a'	b	x_1	x_2	z
4	AL	BIRMINGHAM	37.1	53.0	-0.66	2.01	21.1	0.517
4	AL	GADSDEN	58.3	83.1	-1.06	2.00	10.1	0.720
4	AL	HUNTSVILLE	68.5	94.4	-1.18	2.00	9.9	0.730
4	AL	MOBILE	51.0	73.5	-0.93	2.00	12.1	0.665
4	AL	MONTGOMERY	51.5	68.7	-0.73	2.00	23.9	0.485
4	AL	TUSCALOOSA	13.2	24.4	-0.41	2.00	10.7	0.595
4	FL	FT. LAUDERDALE	75.8	94.8	-0.85	2.00	24.9	0.463
4	FL	GAINESVILLE	28.0	43.5	-0.59	2.00	19.5	0.532
4	FL	JACKSONVILLE	86.5	116.6	-1.11	2.50	13.0	0.670
4	FL	MIAMI	109.1	124.8	-0.76	2.42	40.0	0.266
4	FL	ORLANDO	101.8	135.4	-1.04	2.00	18.3	0.541
4	FL	PENSACOLA	58.8	77.8	-0.81	2.00	24.4	0.511
4	FL	ST. PETERSBURG	102.6	123.0	-0.93	2.00	25.5	0.442
4	FL	TALLAHASSEE	68.7	88.5	-0.85	2.00	21.9	0.501
4	FL	TAMPA	124.2	146.8	-1.04	2.00	22.1	0.473
4	FL	WEST PALM BEACH	47.3	66.6	-0.79	2.00	17.1	0.570
4	GA	ALBANY	26.4	35.9	-0.57	2.00	56.8	0.432
4	GA	ATLANTA	31.4	44.6	-0.58	1.63	33.4	0.486
4	GA	AUGUSTA	46.8	63.9	-0.72	2.00	28.4	0.505
4	GA	COLUMBUS	25.3	40.7	-0.61	2.00	14.4	0.592
4	GA	MACON	47.5	65.0	-0.73	2.00	21.4	0.513
4	GA	SAVANNAH	60.1	79.1	-0.81	2.00	21.7	0.506
4	KY	HUNTINGTON METRO	27.4	41.5	-0.57	2.00	19.5	0.531
4	KY	LEXINGTON	51.0	63.0	-0.61	1.64	44.4	0.349
4	KY	LOUISVILLE	113.8	133.2	-0.92	2.00	29.7	0.393
4	KY	OWENSBORO	57.5	69.4	-0.61	2.00	54.0	0.304
4	MS	BILOXI	24.3	39.8	-0.61	2.00	13.5	0.605
4	MS	JACKSON	48.5	65.9	-0.72	2.13	23.3	0.496
4	NC	ASHEVILLE	89.3	113.8	-1.06	2.00	15.0	0.605
4	NC	CHARLOTTE	30.3	44.1	-0.57	2.00	23.3	0.496
4	NC	DURHAM	15.9	26.6	-0.41	2.00	16.8	0.536
4	NC	FAYETTEVILLE	28.4	43.5	-0.61	2.00	17.3	0.557
4	NC	GREENSBORO	58.0	77.0	-0.81	2.00	21.0	0.516
4	NC	HIGHPOINT	12.2	23.6	-0.41	2.00	10.8	0.619
4	NC	RALEIGH	26.4	40.1	-0.61	1.29	15.4	0.588
4	NC	WILMINGTON	98.9	123.5	-1.08	2.00	13.8	0.588
4	NC	WINSTON-SALEM	27.6	42.8	-0.61	2.00	16.6	0.565
4	SC	CHARLESTON	26.4	40.6	-0.57	2.00	18.3	0.542
4	SC	COLUMBIA	26.4	39.8	-0.57	1.58	18.3	0.636
4	SC	GREENVILLE	28.5	43.6	-0.61	2.00	17.4	0.556
4	TN	CHATTANOOGA	34.9	52.9	-0.72	2.00	14.7	0.601
4	TN	KNOXVILLE	28.1	45.8	-0.61	1.81	17.1	0.538
4	TN	MEMPHIS	109.6	125.2	-0.92	2.00	26.8	0.407
4	TN	NASHVILLE	84.9	119.5	-1.14	2.64	11.9	0.708

TABLE III-9 VALUES OF COEFFICIENTS

EPA RFG	STATE ID	URBANIZED AREA	VALUES OF COEFFICIENTS					
			a	a'	b	x_1	x_2	7
5	IL	AURORA	100.6	121.1	-0.93	2.00	25.1	0.448
5	IL	BLOOMINGTON	90.5	108.6	-0.85	2.00	30.6	0.400
5	IL	CHAMPAIGN	105.5	120.7	-0.75	2.00	[illegible]	0.229
5	IL	CHICAGO	189.7	204.0	-0.92	2.00	[illegible]	[illegible]
5	IL	DAVENPORT METRO	18.6	27.6	-0.37	2.00	[illegible]	[illegible]
5	IL	DECATUR	133.6	157.0	-1.08	2.00	[illegible]	[illegible]
5	IL	JOLIET	92.5	80.6	-0.79	2.00	[illegible]	[illegible]
5	IL	PEORIA	79.6	98.8	-0.93	2.00	24.6	0.471
5	IL	ROCKFORD	112.3	132.1	-0.93	2.00	[illegible]	[illegible]
5	IL	SPRINGFIELD	46.4	59.6	-0.61	2.00	37.9	0.389
5	IN	ANDERSON	88.8	95.7	-1.06	2.00	72.7	0.273
5	IN	CHICAGO METRO	105.7	125.2	-0.81	2.00	[illegible]	0.411
5	IN	EVANSVILLE	78.3	[illegible]	-0.74	2.00	[illegible]	[illegible]
5	IN	FORT WAYNE	108.4	128.4	-0.93	2.00	[illegible]	[illegible]
5	IN	INDIANAPOLIS	204.5	245.6	-1.27	2.00	[illegible]	[illegible]
5	IN	LAFAYETTE	26.2	[illegible]	-0.41	2.00	[illegible]	[illegible]
5	IN	MUNCIE	34.4	33.7	-0.41	2.00	[illegible]	[illegible]
5	IN	SOUTH BEND	34.5	[illegible]	-0.69	2.00	[illegible]	[illegible]
5	IN	TERRA HAUTE	14.8	24.6	-0.37	2.00	[illegible]	0.511
5	MI	ANN ARBOR	51.8	64.4	-0.61	2.00	45.5	0.348
5	MI	BAY CITY	99.7	120.3	-0.93	2.00	[illegible]	0.451
5	MI	DETROIT	157.2	[illegible]	-0.93	2.00	[illegible]	[illegible]
5	MI	FLINT	58.8	74.1	-0.70	2.00	[illegible]	0.401
5	MI	GRAND RAPIDS	60.2	101.8	-0.93	2.00	[illegible]	[illegible]
5	MI	JACKSON	14.6	25.6	-0.41	2.00	[illegible]	[illegible]
5	MI	KALAMAZOO	48.4	68.0	-0.61	2.00	[illegible]	[illegible]
5	MI	LANSING	50.8	68.2	-0.61	2.00	[illegible]	[illegible]
5	MI	MUSKEGON	65.9	87.8	-0.92	2.00	16.4	[illegible]
5	MI	SAGINAW	43.8	57.8	-0.61	2.00	40.9	0.404
5	MN	DULUTH	49.0	71.6	-0.93	2.00	[illegible]	[illegible]
5	MN	FARGO METRO	24.2	[illegible]	-0.41	2.00	[illegible]	[illegible]
5	MN	MINNEAPOLIS	116.9	147.8	[illegible]	2.00	[illegible]	[illegible]
5	MN	ROCHESTER	36.1	47.0	-0.51	2.00	27.1	0.368
5	OH	AKRON	87.3	108.4	-0.93	2.00	21.9	0.493
5	OH	CANTON	105.3	125.6	-0.93	2.00	[illegible]	0.437
5	OH	CINCINNATI	131.0	[illegible]	-0.51	2.00	[illegible]	0.415
5	OH	CLEVELAND	450.6	533.9	[illegible]	2.00	[illegible]	0.447
5	OH	COLUMBUS	158.4	180.2	-1.06	2.00	[illegible]	0.609
5	OH	DAYTON	81.2	100.2	[illegible]	2.00	[illegible]	0.443
5	OH	HAMILTON	118.4	142.4	[illegible]	2.00	[illegible]	[illegible]
5	OH	LIMA	31.5	[illegible]	[illegible]	2.00	[illegible]	[illegible]
5	OH	LORAIN	60.1	82.5	-0.93	2.00	[illegible]	[illegible]
5	OH	MANSFIELD	[illegible]	28.1	-0.41	2.00	[illegible]	[illegible]
5	OH	SPRINGFIELD	[illegible]	[illegible]	-0.41	2.00	[illegible]	[illegible]
5	OH	STEUBENVILLE	[illegible]	[illegible]	-0.41	2.00	[illegible]	[illegible]
5	OH	TOLEDO	61.2	76.7	-0.77	2.00	[illegible]	0.458
5	OH	YOUNGSTOWN	63.7	81.0	-0.77	2.00	27.6	0.443
5	WI	APPLETON	116.8	136.3	-0.93	2.00	29.4	0.393
5	WI	DULUTH METRO	39.0	63.8	-1.06	2.00	6.9	0.403
5	WI	GREEN BAY	21.2	37.0	-0.61	2.00	40.8	0.444
5	WI	KENOSHA	21.6	39.7	-0.41	2.00	41.0	0.490
5	WI	LA CROSSE	[illegible]	[illegible]	-0.59	2.00	[illegible]	[illegible]
5	WI	MADISON	101.3	128.1	-0.53	[illegible]	[illegible]	[illegible]
5	WI	MILWAUKEE	[illegible]	[illegible]	-0.51	2.17	[illegible]	[illegible]
5	WI	OSHKOSH	28.7	37.9	-0.41	2.00	[illegible]	[illegible]
5	WI	RACINE	54.8	66.7	-0.61	2.00	[illegible]	0.330

TABLE III-9 VALUES OF COEFFICIENTS

EPA REG	STATE ID	URBANIZED AREA	VALUES OF COEFFICIENTS a	a'	b	x_1	x_2	7
6	AR	FORT SMITH	59.7	84.5	-1.06	2.00	11.3	0.718
6	AR	LITTLE ROCK	11.6	19.6	-0.34	0.20	15.3	0.536
6	AR	PINE BLUFF	27.6	39.8	-0.51	2.00	27.9	0.462
6	LA	BATON ROUGE	46.4	61.5	-0.68	1.74	26.3	0.459
6	LA	LAFAYETTE	29.6	41.5	-0.51	2.00	33.0	0.437
6	LA	LAKE CHARLES	30.7	44.8	-0.58	2.00	22.5	0.503
6	LA	MONROE	15.1	25.7	-0.41	1.74	14.8	0.550
6	LA	NEW ORLEANS	223.6	228.0	-0.75	2.00	95.3	0.648
6	LA	SHREVEPORT	28.5	42.5	-0.57	2.00	21.0	0.516
6	NM	ALBUQUERQUE	57.5	75.6	-0.79	1.87	21.9	0.501
6	OK	LAWTON	14.7	25.7	-0.41	2.00	14.0	0.560
6	OK	OKLAHOMA CITY	91.3	116.6	-1.11	2.00	13.6	0.635
6	OK	TULSA	68.0	90.4	-0.93	2.06	16.7	0.576
6	TX	ABILENE	66.6	92.5	-1.14	2.00	9.6	0.736
6	TX	AMARILLO	68.3	90.3	-0.93	2.00	16.8	0.575
6	TX	AUSTIN	49.5	65.0	-0.68	2.00	18.9	0.442
6	TX	BEAUMONT	82.5	108.0	-1.11	2.00	22.4	0.663
6	TX	BROWNSVILLE	24.0	33.3	-0.41	2.00	45.4	0.391
6	TX	BRYAN	82.5	107.8	-1.11	2.00	12.4	0.663
6	TX	CORPUS CHRISTI	87.4	112.8	-1.11	2.00	12.4	0.647
6	TX	DALLAS	240.6	284.6	-1.36	2.00	17.2	0.390
6	TX	EL PASO	134.7	161.3	-1.04	2.22	23.9	0.471
6	TX	FORT WORTH	91.2	116.5	-1.11	2.61	13.6	0.635
6	TX	GALVESTON	32.8	46.9	-0.59	2.00	24.1	0.489
6	TX	HARLINGEN	9.9	21.6	-0.41	2.00	5.3	0.677
6	TX	HOUSTON	36.9	50.2	-0.58	2.00	30.8	0.437
6	TX	LAREDO	30.2	42.0	-0.51	2.00	33.3	0.429
6	TX	LUBBOCK	25.1	40.5	-0.61	2.00	14.1	0.596
6	TX	MCALLEN	16.4	25.9	-0.37	2.00	24.4	0.461
6	TX	MIDLAND	12.7	23.9	-0.41	2.00	9.7	0.606
6	TX	ODESSA	31.2	42.8	-0.51	2.00	35.3	0.418
6	TX	PORT ARTHUR	20.5	36.2	-0.61	2.00	10.1	0.656
6	TX	SAN ANGELO	12.7	24.0	-0.41	2.00	9.8	0.607
6	TX	SAN ANTONIO	112.0	131.4	-0.92	2.00	29.1	0.399
6	TX	SHERMAN	10.6	22.2	-0.41	2.00	6.3	0.659
6	TX	TEXARKANA	12.6	23.9	-0.41	2.00	9.8	0.608
6	TX	TEXAS CITY	47.7	72.4	-1.06	2.00	8.3	0.764
6	TX	TYLER	29.2	43.7	-0.59	2.00	19.8	0.529
6	TX	WACO	62.3	87.1	-1.06	2.00	10.7	0.704
6	TX	WICHITA FALL	15.7	26.5	-0.41	2.00	16.5	0.538

TABLE III-9 VALUES OF COEFFICIENTS

EPA REG	STATE ID	URBANIZED AREA	VALUES OF COEFFICIENTS					
			a	a'	b	x_1	x_2	z
7	IA	CEDAR RAPIDS	27.4	42.6	-0.61	2.00	16.4	0.568
7	IA	DAVENPORT	45.7	60.3	-0.93	2.00	10.8	0.694
7	IA	DES MOINES	82.0	109.7	-0.93	2.54	20.2	0.537
7	IA	DUBUQUE	23.2	32.7	-0.41	2.00	41.9	0.403
7	IA	SIOUX CITY	75.4	100.2	-1.06	2.00	12.8	0.654
7	IA	WATERLOO	21.1	36.8	-0.61	2.00	10.6	0.647
7	KS	KANSAS CITY METRO	51.4	66.7	-0.68	2.00	30.5	0.429
7	KS	TOPEKA	46.8	64.2	-0.73	1.93	21.0	0.516
7	KS	WICHITA	35.5	49.8	-0.60	2.00	26.9	0.466
7	MO	COLUMBIA	66.2	91.0	-1.06	2.00	11.4	0.689
7	MO	KANSAS CITY	24.1	38.8	-0.58	2.00	14.9	0.483
7	MO	SPRINGFIELD	44.7	64.5	-0.81	2.00	15.2	0.600
7	MO	ST.JOSEPH	28.6	38.6	-0.58	2.00	70.3	0.297
7	MO	ST.LOUIS	136.0	156.1	-0.91	2.53	38.2	0.338
7	NE	LINCOLN	63.4	80.4	-0.79	1.74	25.3	0.458
7	NE	OMAHA	108.7	128.8	-0.93	2.00	27.1	0.621
8	CO	BOULDER	102.6	116.3	-0.77	2.00	51.4	0.270
8	CO	COLORADO SPRINGS	29.3	44.3	-0.61	2.00	18.3	0.546
8	CO	DENVER	119.5	140.9	-0.92	2.51	32.0	0.387
8	CO	PUEBLO	38.7	51.4	-0.58	2.00	32.7	0.425
8	MT	BILLINGS	32.0	46.2	-0.59	2.00	23.1	0.497
8	MT	GREAT FALLS	32.0	45.1	-0.51	3.14	37.3	0.424
8	ND	FARGO	22.5	30.7	-0.41	0.50	39.1	0.397
8	SD	SIOUX FALLS	31.7	43.8	-0.59	0.97	22.8	0.478
8	UT	OGDEN	57.2	76.3	-0.81	2.00	20.6	0.520
8	UT	PROVO	75.4	100.2	-1.06	2.00	12.8	0.654
8	UT	SALT LAKE CITY	72.1	93.1	-0.86	2.23	22.4	0.501
8	WY	URBAN AREAS	31.7	46.0	-0.59	2.00	22.9	0.500

TABLE III-9 VALUES OF COEFFICIENTS

EPA REG	STATE ID	URBANIZED AREA	VALUES OF COEFFICIENTS					
			a	a'	b	x_1	x_2	7
9	AK	URBAN AREAS	90.2	114.7	-1.04	2.00	15.2	0.601
9	AZ	PHOENIX	130.6	166.9	-1.09	3.22	20.2	0.554
9	AZ	TUCSON	33.8	47.2	-0.60	1.63	24.4	0.675
9	CA	BAKERSFIELD	81.9	100.8	-0.85	2.00	26.7	0.440
9	CA	FRESNO	53.7	68.8	-0.85	2.00	32.5	0.413
9	CA	LOS ANGELES	103.7	116.8	-0.75	2.00	54.5	0.248
9	CA	MODESTO	37.0	50.8	-0.58	2.00	31.0	0.437
9	CA	OXNARD	72.6	96.5	-0.93	2.00	17.7	0.559
9	CA	SACRAMENTO	69.7	90.7	-0.85	2.31	22.6	0.501
9	CA	SALINAS	63.8	82.2	-0.81	2.00	28.6	0.334
9	CA	SAN BERNARDINO	100.5	132.7	-1.11	2.00	14.5	0.404
9	CA	SAN DIEGO	80.0	98.8	-0.84	2.00	27.5	0.438
9	CA	SAN FRANCISCO	638.6	676.5	-1.41	2.34	50.6	0.348
9	CA	SAN JOSE	117.8	138.8	-0.93	2.00	31.5	0.372
9	CA	SANTA BARBARA	65.8	88.1	-0.81	2.00	27.1	0.393
9	CA	SANTA ROSA	13.3	32.8	-0.81	2.00	11.0	0.593
9	CA	SEASIDE	36.3	35.3	-0.81	2.00	56.8	0.459
9	CA	SIMI VALLEY	27.1	61.6	-0.58	2.00	18.1	0.546
9	CA	STOCKTON	44.3	57.8	-0.81	2.00	35.3	0.605
9	HI	HONOLULU	100.8	118.1	-0.85	2.01	34.7	0.360
9	NV	LAS VEGAS	65.0	87.2	-0.93	2.00	15.7	0.594
9	NV	RENO	29.1	40.8	-0.54	0.82	20.6	0.697
10	ID	BOISE	16.5	25.0	-0.37	0.84	25.9	0.659
10	OR	EUGENE	47.8	65.3	-0.73	2.00	21.6	0.511
10	OR	PORTLAND	82.9	102.8	-0.85	2.13	27.2	0.460
10	OR	SALEM	29.9	44.0	-0.58	2.00	21.4	0.513
10	WA	SEATTLE	78.0	97.8	-0.84	2.25	26.7	0.451
10	WA	SPOKANE	47.6	63.3	-0.85	2.00	39.0	0.457
10	WA	TACOMA	57.4	76.1	-0.79	2.00	21.9	0.506

ABBREVIATIONS AND SYMBOLS

a	Coefficient
a'	Adjusted coefficient
A	Total area of urbanized area, acres
b	Coefficient
C	Urban area with computed population density
E	Urban area with estimated population density
P	Population of urbanized area
P_c	Population served by combined sewer system, persons
P_s	Population served by storm sewer system, persons
P_u	Unsewered population, persons
PD	Gross population density, persons per acre
$PD_{x_1-x_2}$	Average population density in interval from x_1 to x_2, persons per acre
PD_{calc}	Calculated average population density, persons per acre
PD_d	Population density in developed portion of urban area, persons per acre
r	Correlation coefficient
x	Percent of urbanized area
x_1	Calibrated lower limit on x such that average PD corresponds to the integrated average PD
x_2	Calibrated upper limit on x such that average PD corresponds to the integrated average PD and percent of urban area which is sewered
x_c	Combined sewer area as percent of urbanized area
x_u	Undeveloped area as percent of urbanized area
Z	Proportion undeveloped area

REFERENCES

1. US Bureau of the Census, County and City Data Book, 1972, USGPO, 1972.

2. American Public Works Association and University of Florida, "Evaluation of the Magnitude and Significance of Pollution Loading from Urban Stormwater Runoff - Ontario," Environmental Protection Service and Ontario Ministry of Environment, Toronto, 1976.

3. Manvel, A. D., Gustafson, R. H. and Welch, R. B., "Three Land Research Studies," National Commission on Urban Problems, Research Report 12, Washington, DC, 1968.

4. US Environmental Protection Agency, "1968 Inventory of Municipal Waste Facilities - A Cooperative State Report," 1971.

5. American Public Works Association, "Problems of Combined Sewer Facilities and Overflows," USEPA Report No. 11020---12/67 (WP-20-11), NTIS PB 217 469, 1967.

6. National Planning Data Corporation, Ithaca, NY.

SECTION IV

QUANTITY ANALYSIS

The purpose of this chapter is to estimate the quantity of urban runoff. The first section provides some background information regarding models which are used to assist in making such decisions. Then, precipitation patterns are analyzed to form a basis for predicting the quantity of urban runoff.

MODELING OF URBAN RUNOFF

The overall goal of urban runoff modeling is to aid in decision making for the abatement of water quantity and quality problems. Thus, computer models do not provide "solutions" to problems, in and of themselves. Rather, they serve as useful tools to those charged with devising such solutions. Within this context, sub-objectives of the modeling process may be identified: planning, design, and operation. Models for the latter category are generally site-specific[1,2] and were not considered during this research study. However, numerous models are available for planning and design purposes[3,4] and two -- the Corps of Engineers' Storage, Treatment, Overflow and Runoff Model (STORM) and the USEPA Storm Water Management Model (SWMM) respectively -- were involved intimately with the study. However, they are not unique; several other urban runoff models are capable of similar tasks.[5]

Computer models are merely mathematical abstractions of the physics of rainfall-runoff-quality processes and do not necessarily produce accurate or even logical predictions without extensive calibration/verification data. This is in addition to data required as model input, such as topography, land use, rainfall, antecedent conditions, description of drainage system and storage-treatment facilities. Among the principal 1965 findings of the ASCE Council on Urban Water Resources[6] was the serious need for field data on rainfall-runoff-quality for several catchments. Unfortunately, in spite of efforts by Federal (US Geological Survey, Office of Water Resources Technology, USEPA) and other agencies, this need still exists, especially in the area of data for calibration/verification of urban hydrology models. For instance, few new discharge data have been acquired on sewered catchments, using flumes, weirs or other accurate devices rather than conversion of stage gauge readings for determination of flow rates.[7] The state-of-the-art in computation and simulation tools has, thus, outstripped its available calibration/verification data base. However, current analytical techniques will necessarily rely on computer models, especially for planning and design purposes. Hence, the ultimate goal of acquisition of salient field data remains worthwhile and necessary. Throughout this section, gaps in available data for input and calibration/verification will be apparent. But the useful analyses which can still be performed without these data should also be clear.

The modeling procedures developed for the nationwide assessment will be discussed in detail. Two levels of sophistication in the assessment are considered: use of STORM for the development of the parameters used in the assessment methodology described in Section VI, and use of a very simple runoff prediction technique for the 248 urbanized areas of the nationwide assessment itself. Preliminary to both is a description of climatological considerations that influence selection of modeling sites and parameters.

PRECIPITATION ANALYSIS

Any analysis of stormwater runoff must first examine the associated rainfall patterns and volumes. The intensity, duration, and frequency of the rainfall have profound effects on the amount of runoff produced.

Precipitation patterns vary widely across the United States. This variation is found not only in total annual volume, as shown in Figure IV-1, Mean Annual Precipitation in the United States, in Inches, and Regional Boundaries used for Nationwide Assessment, but also in the seasonal distribution as shown in Figure IV-2, Month-to-Month Variation of Precipitation in the United States. Among the more dominant regional characteristics are the dry summers on the West Coast, the abrupt changes in the desert states such as Arizona, the peaks occurring in spring and winter in the Central Gulf and Ohio Valley states, and the uniformity of monthly totals throughout the year in the New England states.

In order to analyze the effect that precipitation patterns have on runoff patterns, and thus control alternatives, study areas were chosen which reflected varying rainfall characteristics. The five cities which were chosen are listed in Table IV-1, Precipitation Characteristics of Study Areas, along with the regions they represent and the main characteristics which distinguish each city from the others. Further discussion of precipitation characteristics is presented in Section VI.

RUNOFF ANALYSIS USING STORM

STORM was developed by Water Resources Engineers, Inc., for the Hydrologic Engineering Center of the Corps of Engineers.[8,9] The model was designed for planning purposes, i.e., for long-term simulation of many storm events using an hourly time step. For instance, the model has been used to simulate runoff quality and simple storage-treatment options from a 63-year record of hourly rainfalls in San Francisco.[9]

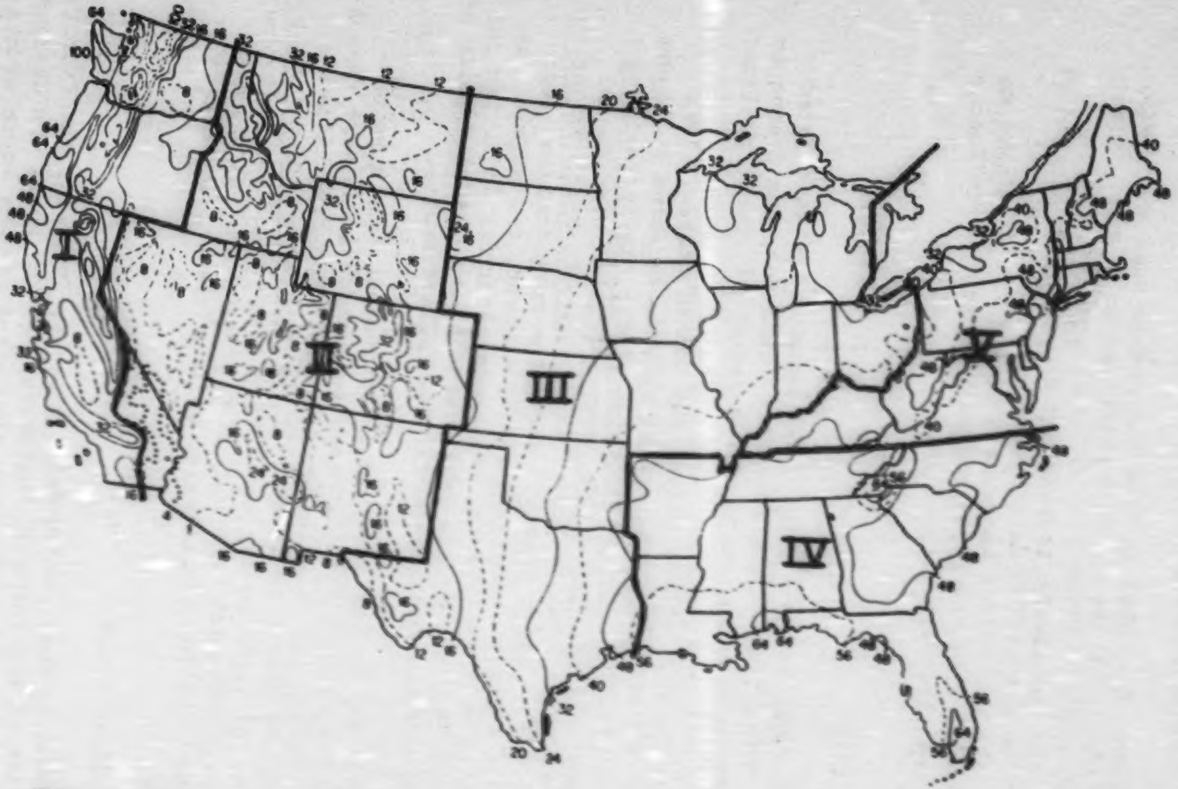

Figure IV-1. Mean Annual Precipitation in the United States, in Inches, and Regional Boundaries Used for Nationwide Assessment

Source: US Weather Bureau Climate Atlas of the United States, 1968

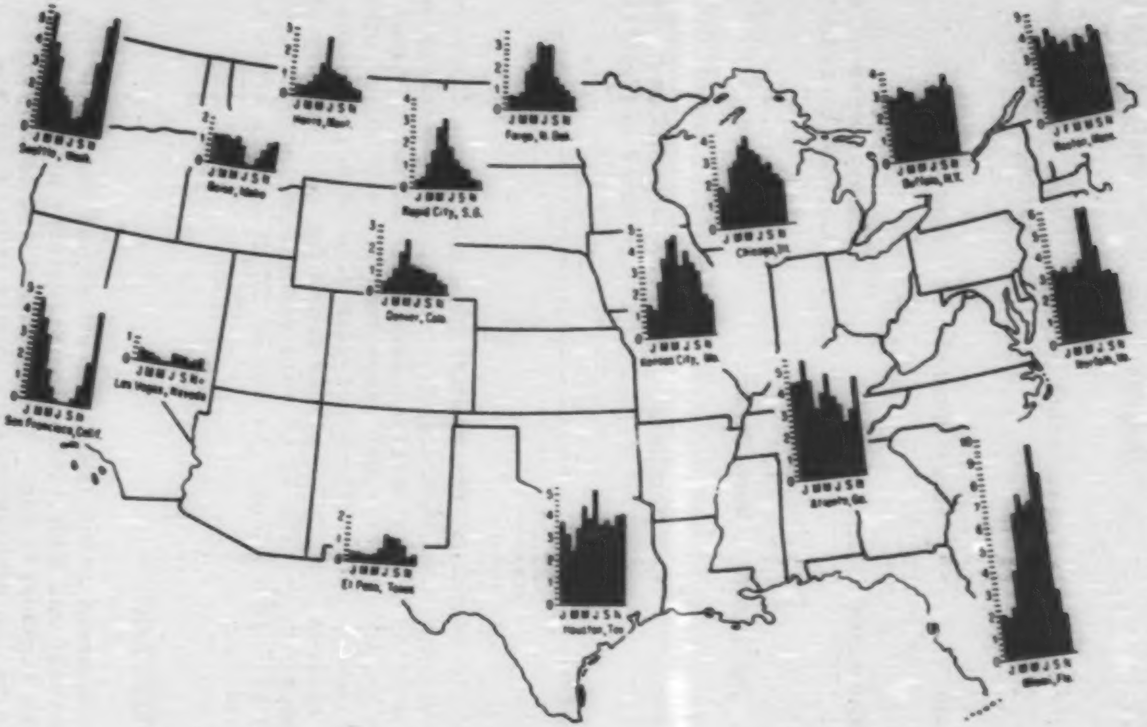
Seattle, Wash.
Havre, Mont.
Fargo, N. Dak.
Boise, Idaho
Rapid City, S.D.
Denver, Colo.
San Francisco, Calif.
Las Vegas, Nevada
El Paso, Texas
Houston, Tex.
Kansas City, Mo.
Chicago, Ill.
Buffalo, N.Y.
Boston, Mass.
Norfolk, Va.
Atlanta, Ga.
Miami, Fla.
J M M J S N

Figure IV-2. Month-to-Month Variation of Precipitation in the United States

Source: US Weather Bureau Climate Atlas of the United States, 1968

TABLE IV-1. PRECIPITATION CHARACTERISTICS OF STUDY AREAS

City	Region	Characteristics
Atlanta, Georgia	Southeast	Large volume; peaks in spring
Denver, Colorado	Rocky Mountain	Low volume
Minneapolis, Minnesota	Midwest	Large number of events; uniform distribution
San Francisco, California	West Coast	Dry summers
Washington, D. C.	Northeast	Large volume; peaks in summer and winter

When STORM is used for planning, the primary objective is to illustrate the effect of various storage-treatment combinations at the downstream end of an entire urban catchment that provide given levels of control. "Level of control" may refer to percent of runoff captured, percent BOD or other pollutant removed, number of overflows per year eliminated, quantity of overflow per year reduced, etc. Use of the model for this primary objective is described in detail in Section VI of this report, including a discussion of the methodology employed. Thus, the use of STORM in this study is deferred to that section.

RUNOFF ANALYSIS USING SWMM

The Storm Water Management Model (SWMM) was developed for the USEPA in 1969-1970 by Metcalf and Eddy, Inc., the University of Florida, and Water Resources Engineers, Inc. It was formulated as a design model, in that a detailed simulation of a single storm event was desired. This is characterized by relatively short-time steps and simulation times (i.e., minutes and hours, respectively) and a relatively high degree of detail in the catchment schematization. Recently, the SWMM has been adapted to planning purposes as well[10], but that use was not applied during this research.

The SWMM methodology, verification and usage are well documented in the original final reports[11,12,13,14] and in more recent publications[15,16] and will not be described here. In general, the SWMM provides a complete description (in both a spatial and temporal sense) of flows and pollutant concentrations from the point of rainfall, through the surface and subsurface drainage network, through storage-treatment facilities, and into the receiving waters.

During formulation of the research plan, it was felt that SWMM would play the dominant role in fulfilling the modeling needs of the study. This concept was later revised in light of altered techniques available for accomplishment of project objectives. In particular, it became apparent that detailed modeling of a few cities would not suffice when the nationwide assessment must encompass 248 urbanized areas. Consequently, much simpler means had to be developed for the overall assessment. In addition, the need for long-term simulation developed (e.g., simulation periods on the order of years) for which the SWMM, at the time, was unsuitable. STORM was later adopted for this purpose. Valuable runs of SWMM were still made on catchments in all of the five test cities as described briefly in Volume III, but they served more to enhance the model's usefulness than to aid in the assessment. Hence, these results are being incorporated into updated SWMM documentation (EPA Grant No. R-802411) and are not presented here.

RUNOFF PREDICTION FOR NATIONWIDE ASSESSMENT

Form of Equation

As discussed, techniques for prediction of runoff quantities vary from very simple methods of the Rational Method type to sophisticated models of the nature of SWMM. The technique used in STORM is relatively simple, relying on weighted average runoff coefficients and a simple loss function to predict hourly runoff volumes. Nonetheless, because of the nature of the continuous simulation involved, it is at a considerably higher level, and therefore more complex, than earlier, desk-top techniques.

Due to the complexities and data requirements of STORM, it was not possible to run the model on all cities of the nationwide assessment, or even a majority. Rather, it was run only on the five test cities discussed earlier (plus the Des Moines example of Section VII). However, in its limited application, useful information was learned regarding formulation of a simple runoff prediction method for application to all the cities of the assessment.

Runoff is a function of meteorologic, hydrologic, topographic and demographic factors. On an annual basis, many of the factors may be considered constant, so that runoff is predicted on the basis of differences between areas rather than reflecting seasonal variations within a year. Hence, the prime meteorologic and hydrologic factor is annual precipitation, and other factors are incorporated into a conversion to annual runoff.

These considerations led directly to the use of a simple runoff coefficient method in which runoff is merely a fraction of rainfall. This approach has been used successfully by Miller and Viessman[17] for runoff prediction on an individual storm basis in urban areas. This equation was

$$AR = 1.165(I - 0.17)(P - I_a) \qquad \text{(IV-1)}$$

where AR = runoff, in.,

I = fraction imperviousness,

P = precipitation, in., and

I_a = initial abstraction, in.

The recommended value of I_a, which accounts for depression storage, interception, etc., was between 0.10 and 0.15 in. (0.25 - 0.38 cm) and the equation was deemed valid for a range of imperviousness between 35 and 80 percent. Extrapolation for use on an annual average basis, however, may be questionable, particularly in the matter of how much water should be abstracted out of the cycle on an annual basis. Hence, an equation will be used that is similar in form to equation IV-1, but which is consistent with the STORM simulation runs, described in Section VI, on which the overall assessment is based.

STORM computes a runoff coefficient, CR, weighted between pervious and impervious areas by

$$\begin{aligned} CR &= 0.15(1 - I) + 0.90\,I \qquad \text{(IV-2)} \\ &= 0.15 + 0.75\,I \end{aligned}$$

where I is fraction imperviousness and the coefficients 0.15 and 0.90 are the default values used in STORM for runoff coefficients from pervious and impervious areas, respectively. Note that in both equations IV-1 and IV-2, the effect of demographic factors (e.g., land use, population density) is incorporated into the imperviousness, I.

Graham et al. (Washington, DC), the American Public Works Association (Volume III), and Stankowski (New Jersey) have developed equations to predict imperviousness as a function of population density.[18,19] The imperviousness is to be estimated for the developed portion of the urbanized area only. Also the weighted average imperviousness and population density were calculated for nine Ontario cities.[20] These results are plotted on Figure IV-3, Imperviousness as a Function of Developed Population Density, along with the three estimating curves. Also, a tabulation was made of the imperviousness due to streets alone for

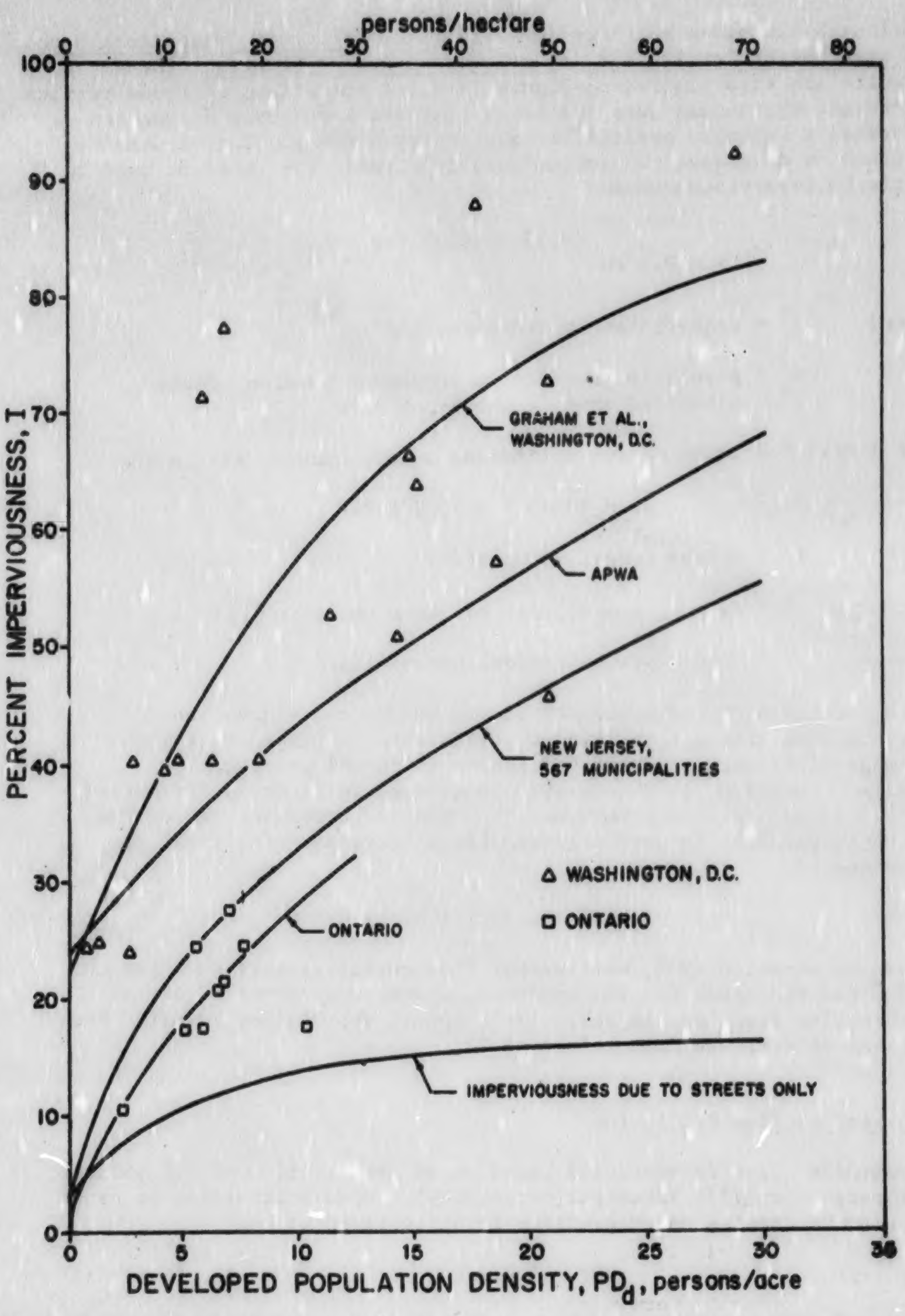

Figure IV-3. Imperviousness as a Function of Developed Population Density

various block sizes as shown in Table IV-2, Effect of Urban Block Size on Curb Length Density and Imperviousness Due to Streets. These results are also plotted on Figure IV-3. A comparison of these various plots and the actual data indicates that the New Jersey[19] equation provides a suitable predictive equation with the population density defined as developed population density. Thus, the equation used to estimate imperviousness is

$$I = 9.6\, PD_d^{(0.573-0.0391 \log_{10} PD_d)} \qquad \text{(IV-3)}$$

where I = imperviousness, percent, and

PD_d = population density in developed portion of the urbanized area, persons per acre.

The simplified equation for estimating annual runoff (AR) is now

$$AR = (0.15 + 0.75\, I/100)P \qquad \text{(IV-4)}$$

where AR = annual runoff, inches/year,

I = imperviousness, percent, from equation IV-3, and

P = annual precipitation, inches/year.

A comparison of STORM simulated runoff versus calculated runoff for the five test cities using equation IV-4 indicated that the average difference is about 0.3 inches (0.76 cm) per year. A similar comparison in the Ontario assessment indicated a difference of 0.5 inches (1.27 cm) per year.[20] Thus, a correction factor was added to equation IV-4 to reflect this difference. The final equation is

$$AR = (0.15 + 0.75\, I/100)P - 0.3 \qquad \text{(IV-5)}$$

Based on equation IV-5, wet-weather flow estimates were made for the 248 urbanized areas for the combined, storm, and unsewered areas. The results are shown in Table IV-3, Annual Wet-Weather Runoff. Precipitation data are from reference 21.

Dry-Weather Flow Prediction

Dry-weather flow is predicted based on an average flow of 100 gallons per person-day (379 liters per person-day). Upon multiplication by population density and conversion to appropriate units,

$$DWF = 1.34\, PD_d \qquad \text{(IV-6)}$$

Table IV-2. EFFECT OF URBAN BLOCK SIZE ON CURB LENGTH DENSITY AND IMPERVIOUSNESS DUE TO STREETS

Block Size ftxft (mxm)	Area, ac (ha)	Curb Length Density ft/ac (m/ha)	Imperviousness due to Streets[a]
660 x 330 (201 x 101)	5 (2.02)	392.0 (295.0)	0.150
1320 x 660 (402 x 201)	20 (8.09)	198.0 (149.0)	0.077
2640 x 1320 (805 x 402)	80 (32.40)	99.0 (74.6)	0.039
5280 x 2640 (1609 x 805)	100 (40.50)	49.5 (37.3)	0.019

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[a] Assumes 34 ft (10.4m) wide street.

TABLE IV-3 ANNUAL WET-WEATHER RUNOFF

EPA RFG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	WET-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
1	CT	BRIDGEPORT	42.0	17.8	17.5	13.0	15.5
1	CT	BRISTOL	43.0	0.0	18.9	12.4	15.4
1	CT	DANBURY	42.0	0.0	17.6	12.4	14.6
1	CT	HARTFORD	42.0	18.2	18.2	12.8	16.0
1	CT	MERIDEN	45.0	0.0	19.2	13.2	15.7
1	CT	NEW BRITAIN	43.0	0.0	17.6	13.9	16.2
1	CT	NEW HAVEN	45.0	18.8	18.8	14.2	16.8
1	CT	NORWALK	44.0	28.5	13.4	13.8	16.1
1	CT	STAMFORD	45.0	0.0	18.8	14.2	16.4
1	CT	WATERBURY	46.0	19.5	19.5	14.2	16.9
1	CT	OTHER URBAN AREAS	43.7	18.8	18.1	13.4	16.1
1	CT	AVE. FOR STATE	43.7	18.8	18.1	13.4	16.1
1	ME	LEWISTON	44.0	17.0	0.0	12.3	15.1
1	ME	PORTLAND	43.0	15.3	0.0	15.3	15.3
1	ME	OTHER URBAN AREAS	43.5	16.0	0.0	13.6	15.2
1	ME	AVE. FOR STATE	43.5	16.0	0.0	13.6	15.2
1	MA	BOSTON	43.0	19.9	19.9	12.4	16.6
1	MA	BROCKTON	45.0	0.0	19.1	14.0	16.6
1	MA	FALL RIVER	45.0	19.7	19.2	13.9	16.9
1	MA	FITCHBURG	46.0	19.4	19.4	13.5	16.0
1	MA	LAWRENCE	41.0	18.2	0.0	13.5	14.9
1	MA	LOWELL	40.0	17.6	17.6	11.8	14.5
1	MA	NEW BEDFORD	41.0	16.8	16.5	13.3	15.6
1	MA	PITTSFIELD	44.0	0.0	18.8	12.9	15.4
1	MA	SPRINGFIELD	45.0	16.2	0.0	16.2	16.2
1	MA	WORCESTER	46.0	21.5	18.7	14.6	17.1
1	MA	OTHER URBAN AREAS	43.6	17.6	19.6	13.2	16.4
1	MA	AVE. FOR STATE	43.6	17.6	19.6	13.2	16.4
1	NH	MANCHESTER	40.0	15.8	0.0	12.5	14.5
1	NH	NASHUA	42.0	14.9	0.0	14.9	14.9
1	NH	OTHER URBAN AREAS	41.0	15.4	0.0	13.5	14.7
1	NH	AVE. FOR STATE	41.0	15.4	0.0	13.5	14.7
1	RI	PROVIDENCE	40.0	18.5	16.5	12.0	15.0
1	RI	OTHER URBAN AREAS	40.0	18.5	16.5	12.0	15.0
1	RI	AVE. FOR STATE	40.0	18.5	16.5	12.0	15.0
1	VT	URBAN AREAS	35.0	13.1	0.0	12.6	12.8
1	VT	AVE. FOR STATE	35.0	13.1	0.0	12.6	12.8
1		AVE. FOR REGION 1	41.1	17.2	18.9	13.2	16.0
2	NJ	ATLANTIC CITY	42.0	0.0	18.5	12.1	15.0
2	NJ	NEW YORK CITY METRO	43.0	20.6	19.6	12.1	15.9
2	NJ	PHILADELPHIA METRO	43.0	16.8	0.0	10.3	16.7
2	NJ	TRENTON	42.0	0.0	17.2	13.6	16.4
2	NJ	VINELAND	44.0	0.0	17.7	13.3	15.1
2	NJ	AVE. FOR STATE	42.8	19.1	19.4	12.2	15.9
2	NY	ALBANY	38.0	16.8	16.8	11.2	14.2
2	NY	BINGHAMPTON	36.0	13.9	13.0	11.7	13.5
2	NY	BUFFALO	36.0	17.0	13.7	11.2	14.8
2	NY	NEW YORK CITY	43.0	35.0	24.8	0.0	29.8
2	NY	ROCHESTER	32.0	15.1	15.1	9.1	12.3
2	NY	SYRACUSE	38.0	15.9	15.9	12.0	14.6
2	NY	UTICA	44.0	18.4	18.4	13.9	16.0
2	NY	OTHER URBAN AREAS	38.1	25.8	21.4	11.0	21.1
2	NY	AVE. FOR STATE	38.1	25.8	21.4	11.0	21.1
2		AVE. FOR REGION 2	40.5	25.2	20.3	11.9	18.2

TABLE IV-3 ANNUAL WET-WEATHER RUNOFF

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	WET-WEATHER FLOW (INCHES PER YEAR)			
				COMP	STORM	UNSEW	AVER
3	DE	WILMINGTON	45.0	19.0	19.0	14.2	17.0
3	DE	OTHER URBAN AREAS	45.0	19.0	19.0	14.2	17.0
3	DE	AVE. FOR STATE	45.0	19.0	19.0	14.2	17.0
3	DC	WASHINGTON, D.C.	41.0	24.8	18.2	0.0	20.7
3	DC	AVE. FOR STATE	41.0	24.8	18.2	0.0	20.7
3	MD	BALTIMORE	43.0	0.0	18.7	13.4	17.3
3	MD	WASHINGTON DC METRO	41.0	0.0	18.0	12.4	15.8
3	MD	OTHER URBAN AREAS	42.0	0.0	18.5	13.1	16.9
3	MD	AVE. FOR STATE	42.0	0.0	18.5	13.1	16.9
3	PA	ALLENTOWN	44.0	19.2	19.2	13.4	16.8
3	PA	ALTOONA	44.0	18.0	18.0	14.3	17.1
3	PA	ERIE	38.0	15.7	15.4	12.3	14.6
3	PA	HARRISBURG	38.0	16.8	16.8	11.2	14.2
3	PA	JOHNSTOWN	45.0	17.7	17.7	15.4	17.0
3	PA	LANCASTER	43.0	17.5	17.5	14.0	16.0
3	PA	PHILADELPHIA	43.0	19.3	18.3	13.6	17.5
3	PA	PITTSBURGH	37.0	19.1	19.1	9.4	13.8
3	PA	READING	42.0	0.0	17.2	13.6	16.3
3	PA	SCRANTON	39.0	14.6	0.0	12.8	14.0
3	PA	WILKES-BARRE	39.0	16.3	16.3	12.2	14.3
3	PA	YORK	40.0	0.0	16.0	13.3	15.1
3	PA	OTHER URBAN AREAS	41.0	17.6	18.2	11.4	15.9
3	PA	AVE. FOR STATE	41.0	17.6	18.2	11.4	15.9
3	VA	LYNCHBERG	40.0	13.8	0.0	0.0	13.8
3	VA	NEWPORT NEWS	45.0	0.0	19.3	13.5	16.0
3	VA	NORFOLK	45.0	0.0	20.2	12.8	16.3
3	VA	PETERSBURG	43.0	0.0	19.4	12.3	15.8
3	VA	RICHMOND	44.0	18.8	18.8	13.6	16.3
3	VA	ROANOKE	42.0	17.2	17.2	13.8	15.5
3	VA	WASHINGTON DC METRO	41.0	19.0	18.2	0.0	18.2
3	VA	OTHER URBAN AREAS	42.9	16.9	18.7	13.2	16.6
3	VA	AVE. FOR STATE	42.9	16.9	18.7	13.2	16.6
3	WV	CHARLESTON	45.0	19.0	19.0	13.9	16.5
3	WV	HUNTINGTON	40.0	14.7	0.0	0.0	14.7
3	WV	STEUBENVILLE METRO	40.0	13.3	0.0	0.0	13.3
3	WV	WHEELING	39.0	15.3	15.3	13.3	14.7
3	WV	OTHER URBAN AREAS	41.0	15.4	18.6	13.8	15.2
3	WV	AVE. FOR STATE	41.0	15.4	18.6	13.8	15.2
3		AVE. FOR REGION 3	42.1	17.4	18.4	12.2	16.3

TABLE IV-3 ANNUAL WET-WEATHER RUNOFF

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	WET-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
4	AL	BIRMINGHAM	53.0	0.0	21.9	17.1	19.4
4	AL	GADSDEN	55.0	0.0	24.2	16.3	19.2
4	AL	HUNTSVILLE	52.0	0.0	22.0	15.1	18.1
4	AL	MOBILE	68.0	0.0	28.8	20.7	24.1
4	AL	MONTGOMERY	54.0	0.0	22.8	17.0	20.0
4	AL	TUSCALOOSA	53.0	0.0	20.8	18.3	19.0
4	AL	OTHER URBAN AREAS	55.8	0.0	23.4	17.7	20.3
4	AL	AVE. FOR STATE	55.8	0.0	23.4	17.7	20.3
4	FL	FT.LAUDERDALE	60.0	0.0	26.0	18.3	22.4
4	FL	GAINESVILLE	52.0	0.0	21.3	17.0	19.0
4	FL	JACKSONVILLE	53.0	0.0	22.4	15.6	18.7
4	FL	MIAMI	60.0	0.0	25.8	18.9	23.9
4	FL	ORLANDO	51.0	22.7	22.7	14.8	18.5
4	FL	PENSACOLA	63.0	0.0	26.9	19.5	23.2
4	FL	ST.PETERSBURG	55.0	0.0	24.4	16.4	20.6
4	FL	TALLAHASSEE	57.0	0.0	24.6	17.4	21.0
4	FL	TAMPA	52.0	0.0	23.6	15.0	19.3
4	FL	WEST PALM BEACH	62.0	0.0	26.2	19.3	22.4
4	FL	OTHER URBAN AREAS	56.5	22.7	24.9	17.1	21.3
4	FL	AVE. FOR STATE	56.5	22.7	24.9	17.1	21.3
4	GA	ALBANY	48.0	16.3	0.0	0.0	16.3
4	GA	ATLANTA	47.0	19.4	19.4	15.3	17.3
4	GA	AUGUSTA	39.0	14.2	0.0	14.2	14.2
4	GA	COLUMBUS	49.0	20.0	20.0	16.0	17.6
4	GA	MACON	44.0	0.0	18.4	13.8	16.1
4	GA	SAVANNAH	52.0	23.9	16.4	16.0	19.1
4	GA	OTHER URBAN AREAS	46.5	18.1	19.2	15.3	17.1
4	GA	AVE. FOR STATE	46.5	18.1	19.2	15.3	17.1
4	KY	HUNTINGTON METRO	40.0	16.2	16.2	13.1	14.5
4	KY	LEXINGTON	44.0	0.0	18.1	14.2	17.0
4	KY	LOUISVILLE	41.0	18.2	18.2	12.2	15.6
4	KY	OWENSBORO	44.0	18.0	18.0	14.3	17.3
4	KY	OTHER URBAN AREAS	42.3	17.9	18.1	12.5	15.8
4	KY	AVE. FOR STATE	42.3	17.9	18.1	12.5	15.8
4	MS	BILOXI	58.0	0.0	23.6	19.1	20.8
4	MS	JACKSON	51.0	0.0	21.3	16.1	18.8
4	MS	OTHER URBAN AREAS	54.5	0.0	22.1	17.5	19.6
4	MS	AVE. FOR STATE	54.5	0.0	22.1	17.5	19.6
4	NC	ASHEVILLE	48.0	0.0	21.1	13.9	17.1
4	NC	CHARLOTTE	43.0	0.0	17.5	14.1	15.8
4	NC	DURHAM	43.0	0.0	17.0	14.7	15.6
4	NC	FAYETTEVILLE	47.0	0.0	19.2	15.3	17.0
4	NC	GREENSBORO	42.0	0.0	17.8	12.9	15.3
4	NC	HIGHPOINT	46.0	0.0	17.8	15.9	16.4
4	NC	RALEIGH	46.0	0.0	19.3	14.8	16.6
4	NC	WILMINGTON	52.0	0.0	23.1	14.9	18.7
4	NC	WINSTON-SALEM	47.0	0.0	19.2	15.3	17.0
4	NC	OTHER URBAN AREAS	46.0	0.0	18.6	14.6	16.4
4	NC	AVE. FOR STATE	46.0	0.0	18.6	14.6	16.4
4	SC	CHARLESTON	47.0	0.0	19.1	15.5	17.1
4	SC	COLUMBIA	47.0	0.0	19.4	15.3	17.1
4	SC	GREENVILLE	46.0	0.0	18.8	15.0	16.6
4	SC	OTHER URBAN AREAS	46.7	0.0	19.1	15.3	17.0
4	SC	AVE. FOR STATE	46.7	0.0	19.1	15.3	17.0
4	TN	CHATTANOOGA	54.0	22.4	22.4	17.2	19.3
4	TN	KNOXVILLE	46.0	0.0	18.9	14.9	16.6
4	TN	MEMPHIS	48.0	0.0	21.3	14.3	18.2
4	TN	NASHVILLE	45.0	19.0	17.6	13.4	15.7
4	TN	OTHER URBAN AREAS	48.3	19.4	20.5	14.6	17.3
4	TN	AVE. FOR STATE	48.3	19.4	20.5	14.6	17.3
4		AVE. FOR REGION 4	49.6	18.5	21.7	15.8	18.6

TABLE IV-3 ANNUAL WET-WEATHER RUNOFF

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL PRECP	WET-WEATHER FLOW (INCHES PER YEAR)			
				COMB	STORM	UNSEW	AVER
5	IL	AURORA	34.0	0.0	15.0	10.0	12.6
5	IL	BLOOMINGTON	36.0	0.0	15.6	10.9	13.6
5	IL	CHAMPAIGN	37.0	0.0	15.8	11.7	13.1
5	IL	CHICAGO	33.0	17.1	10.1	9.9	12.9
5	IL	DAVENPORT METRO	34.0	14.7	15.2	11.7	12.7
5	IL	DECATUR	37.0	13.6	0.0	13.6	12.6
5	IL	JOLIET	33.0	0.0	14.0	10.1	12.1
5	IL	PEORIA	35.0	12.6	0.0	12.6	12.6
5	IL	ROCKFORD	36.0	0.0	16.0	10.6	13.5
5	IL	SPRINGFIELD	35.0	14.3	14.3	11.3	13.3
5	IL	OTHER URBAN AREAS	35.0	16.6	11.6	10.3	13.4
5	IL	AVE. FOR STATE	35.0	16.6	11.6	10.3	13.4
5	IN	ANDERSON	36.0	10.6	0.0	0.0	10.6
5	IN	CHICAGO METRO	33.0	14.5	14.5	9.8	12.9
5	IN	EVANSVILLE	41.0	15.8	0.0	0.0	15.8
5	IN	FORT WAYNE	34.0	15.0	15.0	10.3	12.7
5	IN	INDIANAPOLIS	40.0	17.4	17.4	11.3	14.4
5	IN	LAFAYETTE	35.0	15.6	8.7	10.0	13.6
5	IN	MUNCIE	39.0	15.2	15.2	13.3	14.8
5	IN	SOUTH BEND	36.0	13.4	0.0	14.0	13.2
5	IN	TERRA HAUTE	41.0	0.0	16.1	14.2	15.0
5	IN	OTHER URBAN AREAS	37.2	14.7	15.1	10.9	13.3
5	IN	AVE. FOR STATE	37.2	14.7	15.1	10.9	13.3
5	MI	ANN ARBOR	31.0	0.0	12.6	10.0	11.9
5	MI	BAY CITY	28.0	10.3	0.0	10.3	10.3
5	MI	DETROIT	31.0	13.9	12.9	9.3	12.1
5	MI	FLINT	30.0	12.5	12.5	9.4	11.3
5	MI	GRAND RAPIDR	31.0	13.0	13.8	9.1	12.2
5	MI	JACKSON	34.0	12.7	0.0	11.8	12.2
5	MI	KALAMAZOO	34.0	0.0	14.3	10.4	12.1
5	MI	LANSING	31.0	12.8	12.5	9.8	11.5
5	MI	MUSKEGON	32.0	0.0	13.7	9.5	11.8
5	MI	SAGINAW	28.0	10.5	0.0	10.5	10.5
5	MI	OTHER URBAN AREAS	31.0	13.6	12.9	9.5	11.9
5	MI	AVE. FOR STATE	31.0	13.6	12.9	9.5	11.9
5	MN	DULUTH	29.0	12.1	12.1	8.7	10.1
5	MN	FARGO METRO	21.0	8.1	8.1	7.0	7.8
5	MN	MINNEAPOLIS	25.0	10.5	10.5	7.3	9.0
5	MN	ROCHESTER	29.0	0.0	11.5	9.6	11.0
5	MN	OTHER URBAN AREAS	26.0	10.5	10.6	7.4	9.1
5	MN	AVE. FOR STATE	26.0	10.5	10.6	7.4	9.1
5	OH	AKRON	38.0	0.0	16.6	11.3	13.9
5	OH	CANTON	38.0	17.4	16.7	11.2	14.2
5	OH	CINCINNATI	34.0	13.6	13.6	11.5	12.7
5	OH	CLEVELAND	32.0	15.1	15.1	8.5	11.8
5	OH	COLUMBUS	36.0	16.6	16.6	10.2	13.5
5	OH	DAYTON	35.0	0.0	15.1	10.6	13.0
5	OH	HAMILTON	40.0	18.0	18.0	11.4	14.5
5	OH	LIMA	38.0	12.5	0.0	0.0	12.5
5	OH	LORAIN	35.0	25.8	14.7	10.4	15.4
5	OH	MANSFIELD	43.0	0.0	16.7	14.8	15.3
5	OH	SPRINGFIELD	40.0	15.6	15.6	13.6	15.3
5	OH	STEUBENVILLE	40.0	16.1	0.0	0.0	15.2
5	OH	TOLEDO	32.0	13.6	13.3	9.9	11.8
5	OH	YOUNGSTOWN	42.0	17.8	17.8	13.0	15.7
5	OH	OTHER URBAN AREAS	37.2	14.6	15.6	10.2	12.9
5	OH	AVE. FOR STATE	37.2	14.6	15.6	10.2	12.9
5	WI	APPLETON	29.0	12.8	12.8	8.5	10.9
5	WI	DULUTH METRO	29.0	0.0	11.5	8.7	9.8
5	WI	GREEN BAY	27.0	10.8	10.8	8.8	9.4
5	WI	KENOSHA	32.0	14.1	12.3	0.0	12.6
5	WI	LA CROSSE	31.0	12.6	15.8	10.0	11.3
5	WI	MADISON	31.0	0.0	9.5	9.2	11.4
5	WI	MILWAUKEE	28.0	15.0	4.4	9.2	10.2
5	WI	OSHKOSH	28.0	0.0	10.5	0.0	10.8
5	WI	RACINE	32.0	0.0	13.0	10.3	12.8
5	WI	OTHER URBAN AREAS	29.7	14.5	10.8	9.2	10.5
5	WI	AVE. FOR STATE	29.7	14.5	10.8	9.2	10.5
5		AVE. FOR REGION 5	32.7	14.8	12.9	9.6	12.3

TABLE IV-3 ANNUAL WET-WEATHER RUNOFF

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	WET-WEATHER FLOW (INCHES PER YEAR)			
				COMB	STORM	UNSEW	AVER.
6	AR	FORT SMITH	43.0	15.0	0.0	15.0	15.0
6	AR	LITTLE ROCK	49.0	0.0	20.5	16.7	17.8
6	AR	PINE BLUFF	52.0	0.0	21.0	17.4	19.3
6	AR	OTHER URBAN AREAS	48.0	15.0	20.6	16.4	17.4
6	AR	AVE. FOR STATE	48.0	15.0	20.6	16.4	17.4
6	LA	BATON ROUGE	60.0	0.0	25.3	19.1	22.4
6	LA	LAFAYETTE	59.0	0.0	23.8	19.7	22.2
6	LA	LAKE CHARLES	58.0	0.0	23.7	19.1	21.4
6	LA	MONROE	50.0	0.0	19.9	17.1	18.1
6	LA	NEW ORLEANS	64.0	0.0	31.8	0.0	31.8
6	LA	SHREVEPORT	45.0	0.0	18.3	14.8	16.4
6	LA	OTHER URBAN AREAS	56.0	0.0	27.5	17.4	24.1
6	LA	AVE. FOR STATE	56.0	0.0	27.5	17.4	24.1
6	NM	ALBUQUERQUE	9.0	0.0	3.6	2.5	3.1
6	NM	OTHER URBAN AREAS	9.0	0.0	3.6	2.5	3.1
6	NM	AVE. FOR STATE	9.0	0.0	3.6	2.5	3.1
6	OK	LAWTON	30.0	0.0	11.7	10.2	10.7
6	OK	OKLAHOMA CITY	31.0	0.0	13.5	8.8	10.9
6	OK	TULSA	37.0	0.0	15.9	11.0	13.2
6	OK	OTHER URBAN AREAS	32.7	0.0	14.2	9.7	11.7
6	OK	AVE. FOR STATE	32.7	0.0	14.2	9.7	11.7
6	TX	ABILENE	24.0	0.0	10.0	6.8	8.2
6	TX	AMARILLO	20.0	0.0	8.5	5.8	7.0
6	TX	AUSTIN	33.0	0.0	13.7	10.4	12.2
6	TX	BEAUMONT	54.0	23.5	23.5	15.6	19.1
6	TX	BROWNSVILLE	27.0	0.0	10.5	9.1	10.1
6	TX	BRYAN	39.0	0.0	16.9	11.2	13.7
6	TX	CORPUS CHRISTI	28.0	0.0	12.1	7.9	9.8
6	TX	DALLAS	35.0	0.0	15.3	9.7	12.5
6	TX	EL PASO	8.0	0.0	3.3	2.1	2.7
6	TX	FORT WORTH	30.0	0.0	13.1	8.5	10.5
6	TX	GALVESTON	43.0	27.7	0.0	14.0	15.8
6	TX	HARLINGEN	26.0	0.0	9.4	8.9	9.0
6	TX	HOUSTON	46.0	25.4	18.7	15.0	17.2
6	TX	LAREDO	19.0	0.0	7.5	6.1	7.0
6	TX	LUBBOCK	18.0	0.0	7.1	5.7	6.3
6	TX	MCALLEN	21.0	0.0	8.1	7.1	7.6
6	TX	MIDLAND	14.0	0.0	5.2	4.6	4.8
6	TX	ODESSA	14.0	0.0	5.4	4.5	5.1
6	TX	PORT ARTHUR	54.0	0.0	21.7	17.8	19.1
6	TX	SAN ANGELO	19.0	0.0	7.2	6.4	6.6
6	TX	SAN ANTONIO	28.0	0.0	12.3	8.2	10.5
6	TX	SHERMAN	39.0	0.0	14.6	13.5	13.7
6	TX	TEXARKANA	46.0	0.0	17.9	15.9	16.4
6	TX	TEXAS CITY	45.0	0.0	18.5	13.5	15.5
6	TX	TYLER	45.0	0.0	18.4	14.7	16.4
6	TX	WACO	32.0	0.0	13.5	9.3	11.1
6	TX	WICHITA FALL	29.0	0.0	11.4	9.9	10.4
6	TX	OTHER URBAN AREAS	31.0	24.7	14.2	10.1	12.3
6	TX	AVE. FOR STATE	31.0	24.7	14.2	10.1	12.3
6		AVE. FOR REGION 6.	35.3	17.9	16.2	10.7	13.4

TABLE IV-3 ANNUAL WET-WEATHER RUNOFF

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	WET-WEATHER FLOW (INCHES PER YEAR) COMP	STORM	UNSEW	AVER
7	IA	CEDAR RAPIDS	33.0	0.0	13.4	10.7	11.8
7	IA	DAVENPORT	34.0	14.1	14.1	10.2	11.5
7	IA	DES MOINES	31.0	18.2	10.2	9.3	11.2
7	IA	DUBUQUE	33.0	0.0	12.9	11.2	12.6
7	IA	SIOUX CITY	25.0	0.0	10.7	7.1	8.7
7	IA	WATERLOO	32.0	0.0	12.5	10.4	11.2
7	IA	OTHER URBAN AREAS	31.3	18.0	12.1	9.7	11.1
7	IA	AVE. FOR STATE	31.3	18.0	12.1	9.7	11.1
7	KS	KANSAS CITY METRO	34.0	14.1	14.1	10.7	12.7
7	KS	TOPEKA	34.0	14.2	14.2	10.6	12.3
7	KS	WICHITA	31.0	0.0	12.6	10.0	11.4
7	KS	OTHER URBAN AREAS	33.0	14.1	13.2	10.4	12.1
7	KS	AVE. FOR STATE	33.0	14.1	13.2	10.4	12.1
7	MO	COLUMBIA	37.0	0.0	15.7	10.8	12.9
7	MO	KANSAS CITY	34.0	15.2	11.6	11.1	12.1
7	MO	SPRINGFIELD	41.0	0.0	17.2	12.7	14.6
7	MO	ST.JOSEPH	35.0	11.2	0.0	0.0	11.2
7	MO	ST.LOUIS	37.0	14.3	0.0	14.2	14.3
7	MO	OTHER URBAN AREAS	36.8	14.2	13.3	12.7	13.5
7	MO	AVE. FOR STATE	36.8	14.2	13.3	12.7	13.5
7	NE	LINCOLN	27.0	0.0	11.5	8.2	9.9
7	NE	OMAHA	26.0	11.4	11.4	7.6	9.7
7	NE	OTHER URBAN AREAS	26.5	11.4	11.5	7.7	9.7
7	NE	AVE. FOR STATE	26.5	11.4	11.5	7.7	9.7
7		AVE. FOR REGION 7	31.9	14.0	12.6	10.8	12.2
8	CO	BOULDER	19.0	0.0	8.0	5.8	7.4
8	CO	COLORADO SPRINGS	13.0	0.0	5.1	4.0	4.5
8	CO	DENVER	14.0	7.7	5.9	4.0	5.1
8	CO	PUEBLO	12.0	5.7	4.4	3.7	4.3
8	CO	OTHER URBAN AREAS	14.5	6.1	5.8	4.0	5.1
8	CO	AVE. FOR STATE	14.5	6.1	5.8	4.0	5.1
8	MT	BILLINGS	13.0	0.0	5.1	4.0	4.6
8	MT	GREAT FALLS	15.0	0.0	5.7	4.9	5.4
8	MT	OTHER URBAN AREAS	14.0	0.0	5.4	4.3	5.0
8	MT	AVE. FOR STATE	14.0	0.0	5.4	4.3	5.0
8	ND	FARGO	21.0	8.3	8.3	6.9	7.8
8	ND	OTHER URBAN AREAS	21.0	8.3	8.3	6.9	7.8
8	ND	AVE. FOR STATE	21.0	8.3	8.3	6.9	7.8
8	SD	SIOUX FALLS	25.0	10.4	10.4	7.9	9.1
8	SD	OTHER URBAN AREAS	25.0	10.4	10.4	7.9	9.1
8	SD	AVE. FOR STATE	25.0	10.4	10.4	7.9	9.1
8	UT	OGDEN	17.0	0.0	7.0	5.0	6.0
8	UT	PROVO	13.0	0.0	5.4	3.6	4.4
8	UT	SALT LAKE CITY	15.0	0.0	6.2	4.4	5.3
8	UT	OTHER URBAN AREAS	15.0	0.0	6.3	4.4	5.3
8	UT	AVE. FOR STATE	15.0	0.0	6.3	4.4	5.3
8	WY	URBAN AREAS	15.0	0.0	5.9	4.7	5.3
8	WY	AVE. FOR STATE	15.0	0.0	5.9	4.7	5.3
8		AVE. FOR REGION 8	17.4	7.5	6.4	4.7	5.6

TABLE IV-3 ANNUAL WET-WEATHER RUNOFF

EPA REG	STATE ID	URBANIZED ARFA	TN/YR ANNL PRECP	WET-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
9	AK	URBAN AREAS	30.0	13.1	13.1	8.6	10.6
9	AK	AVE. FOR STATF	30.0	13.1	13.1	8.6	10.6
9	AZ	PHOENIX	7.0	0.0	2.7	1.8	2.3
9	AZ	TUCSON	11.0	0.0	4.3	3.3	3.8
9	AZ	OTHER URBAN AREAS	9.0	0.0	3.1	2.2	2.7
9	AZ	AVE. FOR STATE	9.0	0.0	3.1	2.2	2.7
9	CA	BAKERSFIELD	11.0	0.0	4.5	3.1	3.9
9	CA	FRESNO	11.0	0.0	4.4	3.3	3.9
9	CA	LOS ANGELFS	13.0	0.0	5.3	3.9	4.6
9	CA	MODESTO	25.0	0.0	10.1	8.0	9.2
9	CA	OXNARD	15.0	0.0	6.3	4.3	5.2
9	CA	SACRAMENTO	18.0	7.5	7.5	5.3	6.4
9	CA	SALINAS	15.0	0.0	5.9	4.7	5.6
9	CA	SAN BERNANDINO	18.0	0.0	7.8	4.9	6.2
9	CA	SAN DIEGO	11.0	0.0	4.5	3.1	3.9
9	CA	SAN FRANCISCO	21.0	11.6	9.0	5.6	8.1
9	CA	SAN JOSE	14.0	0.0	6.0	4.0	5.1
9	CA	SANTA BARBARA	18.0	0.0	7.2	5.7	6.7
9	CA	SANTA ROSA	30.0	0.0	11.6	10.2	10.6
9	CA	SEASIDE	16.0	0.0	6.1	5.3	6.0
9	CA	SIMI VALLEY	25.0	0.0	10.0	8.1	8.9
9	CA	STOCKTON	14.0	0.0	5.5	4.3	5.1
9	CA	OTHER URBAN AREAS	17.2	11.3	5.9	4.6	5.7
9	CA	AVE. FOR STATE	17.2	11.3	5.9	4.6	5.7
9	HI	HONOLULU	23.0	0.0	9.9	6.9	8.7
9	HI	OTHER URBAN AREAS	23.0	0.0	9.9	6.9	8.7
9	HI	AVE. FOR STATE	23.0	0.0	9.9	6.9	8.7
9	NV	LAS VEGAS	4.0	0.0	1.4	0.9	1.2
9	NV	RENO	7.0	2.9	2.6	2.0	2.3
9	NV	OTHER URBAN AREAS	5.5	2.9	1.6	1.2	1.5
9	NV	AVE. FOR STATF	5.5	2.9	1.6	1.2	1.5
9		AVE. FOR REGION 9	16.9	10.9	5.8	4.3	5.5
10	ID	BOISE	11.0	0.0	4.2	3.5	3.9
10	ID	OTHER URBAN AREAS	11.0	0.0	4.2	3.5	3.9
10	ID	AVE. FOR STATF	11.0	0.0	4.2	3.5	3.9
10	OR	EUGENE	38.0	15.9	15.9	11.9	13.9
10	OR	PORTLAND	40.0	17.2	17.2	13.1	14.9
10	OR	SALEM	40.0	0.0	16.3	13.1	14.6
10	OR	OTHER URBAN AREAS	39.3	17.2	16.8	12.2	14.7
10	OR	AVE. FOR STATE	39.3	17.2	16.8	12.2	14.7
10	WA	SEATTLE	35.0	14.9	14.9	10.7	13.0
10	WA	SPOKANE	17.0	6.1	0.0	6.1	6.1
10	WA	TACOMA	39.0	16.5	16.5	12.0	14.3
10	WA	OTHER URBAN AREAS	30.3	12.0	15.5	10.6	12.3
10	WA	AVE. FOR STATE	30.3	12.0	15.5	10.6	12.3
10		AVE. FOR REGION 10	26.9	13.5	14.1	10.5	12.4
		AVERAGE FOR THE U.S.	33.4	16.5	14.8	10.8	13.4

where DWF = annual dry-weather flow, inches per year, and

PD_d = developed population density, persons per acre.

Results of these runoff calculations are shown in Table IV-4, Annual Dry-Weather Flow.

Dry-weather flow and wet-weather flow for the developed portion of an urbanized area with a precipitation of 15, 30, or 45 inches per year are shown in Figure IV-4, Comparative Magnitude of Annual Wet- and Dry-Weather Flows. Note that dry-weather flow predominates at higher population densities which have historically prevailed in cities. However, with the trend towards lower density urban living, wet-weather flows take on greater relative importance. Indeed, they are larger than dry-weather flows at the lower population densities.

TABLE IV-4 ANNUAL DRY-WEATHER FLOW

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	DRY-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
1	CT	BRIDGEPORT	42.0	16.6	16.6	6.4	11.2
1	CT	BRISTOL	43.0	0.0	16.6	4.9	10.1
1	CT	DANBURY	42.0	0.0	16.2	5.3	9.3
1	CT	HARTFORD	45.0	17.8	17.8	8.0	12.2
1	CT	MERIDEN	45.0	0.0	16.9	8.2	9.8
1	CT	NEW BRITAIN	43.0	0.0	15.2	7.4	12.0
1	CT	NEW HAVEN	45.0	16.1	16.1	6.8	11.8
1	CT	NORWALK	44.0	49.3	6.0	6.0	10.9
1	CT	STAMFORD	45.0	0.0	16.1	6.7	11.0
1	CT	WATERBURY	46.0	16.7	16.7	6.3	11.0
1	CT	OTHER URBAN AREAS	43.7	18.1	15.9	6.2	11.3
1	CT	AVE. FOR STATE	43.7	18.1	15.9	6.2	11.3
1	ME	LEWISTON	44.0	13.8	0.0	4.4	9.0
1	ME	PORTLAND	43.0	10.1	0.0	10.1	10.1
1	ME	OTHER URBAN AREAS	43.5	11.2	0.0	6.9	9.6
1	ME	AVE. FOR STATE	43.5	11.2	0.0	6.9	9.6
1	MA	BOSTON	43.0	21.2	21.2	4.9	12.8
1	MA	BROCKTON	45.0	0.0	16.7	6.4	11.2
1	MA	FALL RIVER	45.0	17.1	17.1	8.3	11.8
1	MA	FITCHBURG	46.0	18.5	18.5	5.3	9.3
1	MA	LAWRENCE	41.0	15.8	0.0	7.8	10.7
1	MA	LOWELL	40.0	18.7	18.7	5.8	11.4
1	MA	NEW BEDFORD	41.0	15.1	15.1	7.4	12.8
1	MA	PITTSFIELD	44.0	0.0	17.1	5.2	9.5
1	MA	SPRINGFIELD	45.0	10.4	0.0	10.4	10.4
1	MA	WORCESTER	46.0	21.9	18.8	6.9	11.4
1	MA	OTHER URBAN AREAS	43.6	15.2	20.1	6.1	12.0
1	MA	AVE. FOR STATE	43.6	15.2	20.1	6.1	12.0
1	NH	MANCHESTER	40.0	13.6	0.0	6.6	10.7
1	NH	NASHUA	42.0	8.9	0.0	8.9	9.9
1	NH	OTHER URBAN AREAS	41.0	12.1	0.0	8.0	10.4
1	NH	AVE. FOR STATE	41.0	12.1	0.0	8.0	10.4
1	RI	PROVIDENCE	40.0	21.3	15.6	5.6	11.8
1	RI	OTHER URBAN AREAS	40.0	21.3	15.6	5.6	11.8
1	RI	AVE. FOR STATE	40.0	21.3	15.6	5.6	11.8
1	VT	URBAN AREAS	35.0	11.8	0.0	10.4	11.0
1	VT	AVE. FOR STATE	35.0	11.8	0.0	10.4	11.0
1		AVE. FOR REGION 1.	41.1	15.1	18.4	6.3	11.5
2	NJ	ATLANTIC CITY	42.0	0.0	18.7	6.9	10.2
2	NJ	NEW YORK CITY METRO	43.0	44.1	20.6	4.6	11.8
2	NJ	PHILADELPHIA METRO	43.0	13.3	0.0	2.4	10.0
2	NJ	TRENTON	42.0	0.0	13.1	7.5	11.1
2	NJ	VINELAND	44.0	0.0	14.4	5.9	8.9
2	NJ	AVE. FOR STATE	42.8	20.5	19.9	4.6	11.2
2	NY	ALBANY	38.0	18.9	18.9	5.5	11.8
2	NY	BINGHAMPTON	36.0	12.8	0.0	7.4	11.8
2	NY	BUFFALO	36.0	45.3	18.3	6.8	14.4
2	NY	NEW YORK CITY	43.0	65.4	37.9	0.0	49.2
2	NY	ROCHESTER	32.0	22.8	22.8	4.7	13.0
2	NY	SYRACUSE	38.0	18.8	18.8	6.9	12.7
2	NY	UTICA	44.0	16.0	16.0	6.7	10.7
2	NY	OTHER URBAN AREAS	38.1	52.5	29.9	5.9	33.2
2	NY	AVE. FOR STATE	38.1	52.5	29.9	5.9	33.2
2		AVE. FOR REGION 2.	40.5	49.4	24.4	5.0	21.2

TABLE IV-4 ANNUAL DRY-WEATHER FLOW

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL PRECP	DRY-WEATHER FLOW (INCHES PER YEAR)			
				COMB	STORM	UNSEW	AVER
3	DE	WILMINGTON	45.0	16.4	16.4	6.7	12.0
3	DE	OTHER URBAN AREAS	45.0	16.4	16.4	6.7	12.0
3	DE	AVE. FOR STATE	45.0	16.4	16.4	6.7	12.0
3	DC	WASHINGTON,D.C.	41.0	42.2	19.1	0.0	26.9
3	DC	AVE. FOR STATE	41.0	42.2	19.1	0.0	26.9
3	MD	BALTIMORE	43.0	0.0	17.8	6.5	14.4
3	MD	WASHINGTON DC METRO	41.0	0.0	18.4	5.9	12.5
3	MD	OTHER URBAN AREAS	42.0	0.0	18.0	6.3	14.0
3	MD	AVE. FOR STATE	42.0	0.0	18.0	6.3	14.0
3	PA	ALLENTOWN	44.0	18.1	18.1	6.0	12.4
3	PA	ALTOONA	44.0	15.2	15.2	7.4	13.0
3	PA	ERIE	38.0	15.6	14.9	7.4	12.8
3	PA	HARRISBURG	38.0	18.9	18.9	5.5	11.0
3	PA	JOHNSTOWN	43.0	15.4	15.4	8.8	12.0
3	PA	LANCASTER	43.0	14.9	14.9	7.8	12.5
3	PA	PHILADELPHIA	43.0	19.6	17.0	6.9	14.9
3	PA	PITTSBURGH	37.0	28.4	20.4	4.1	11.6
3	PA	READING	42.0	0.0	15.1	7.5	13.0
3	PA	SCRANTON	39.0	11.7	0.0	7.8	10.3
3	PA	WILKES-BARRE	39.0	16.2	16.2	6.7	11.1
3	PA	YORK	40.0	0.0	14.3	8.1	11.9
3	PA	OTHER URBAN AREAS	41.0	20.4	18.0	5.1	13.2
3	PA	AVE. FOR STATE.	41.0	20.4	18.0	5.1	13.2
3	VA	LYNCHBERG	40.0	9.2	0.0	0.0	9.2
3	VA	NEWPORT NEWS	45.0	0.0	17.1	5.6	10.0
3	VA	NORFOLK	45.0	0.0	19.5	4.7	10.5
3	VA	PETERSBURG	43.0	0.0	19.8	4.7	10.7
3	VA	RICHMOND	44.0	18.8	16.9	6.3	10.3
3	VA	ROANOKE	42.0	15.1	15.1	7.8	10.7
3	VA	WASHINGTON DC METRO	41.0	21.5	19.0	0.0	19.0
3	VA	OTHER URBAN AREAS	42.9	14.3	18.7	5.5	13.0
3	VA	AVE. FOR STATE	42.9	14.3	18.7	5.5	13.0
3	WV	CHARLESTON	45.0	16.6	16.6	6.3	10.9
3	WV	HUNTINGTON	40.0	11.0	0.0	0.0	11.0
3	WV	STEUBENVILLE METRO	40.0	8.1	0.0	0.0	8.1
3	WV	WHEELING	39.0	13.5	13.5	8.8	11.9
3	WV	OTHER URBAN AREAS	41.0	12.0	16.2	6.9	10.8
3	WV	AVE. FOR STATE	41.0	12.0	16.2	6.9	10.8
3		AVE. FOR REGION 3.	42.1	18.3	18.1	5.5	13.5

TABLE IV-4 ANNUAL DRY-WEATHER FLOW

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL PRECP	DRY-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
4	AL	BIRMINGHAM	53.0	0.0	15.5	7.1	10.8
4	AL	GADSDEN	54.0	0.0	16.3	5.3	9.3
4	AL	HUNTSVILLE	52.0	0.0	16.6	5.0	9.2
4	AL	MOBILE	68.0	0.0	16.4	5.0	9.6
4	AL	MONTGOMERY	50.0	0.0	16.3	6.6	11.1
4	AL	TUSCALOOSA	53.0	0.0	13.2	6.0	10.1
4	AL	OTHER URBAN AREAS	55.8	0.0	15.8	6.5	10.2
4	AL	AVE. FOR STATE	55.8	0.0	15.8	6.5	10.2
4	FL	FT. LAUDERDALE	60.0	0.0	17.6	5.9	11.3
4	FL	GAINESVILLE	52.0	0.0	15.0	7.6	10.7
4	FL	JACKSONVILLE	55.0	0.0	16.5	5.2	9.8
4	FL	MIAMI	60.0	0.0	17.2	6.6	13.8
4	FL	ORLANDO	51.0	19.1	19.1	5.0	10.6
4	FL	PENSACOLA	68.0	0.0	18.6	6.2	10.9
4	FL	ST. PETERSBURG	55.0	0.0	18.9	5.4	10.8
4	FL	TALLAHASSEE	57.0	0.0	17.8	5.9	10.8
4	FL	TAMPA	52.0	0.0	20.0	6.0	11.2
4	FL	WEST PALM BEACH	62.0	0.0	16.4	4.4	10.3
4	FL	OTHER URBAN AREAS	56.5	19.1	17.4	5.7	11.5
4	FL	AVE. FOR STATE	56.5	19.1	17.4	5.7	11.5
4	GA	ALBANY	48.0	8.5	0.0	0.0	8.5
4	GA	ATLANTA	47.0	15.8	15.4	7.5	11.1
4	GA	AUGUSTA	39.0	10.9	0.0	10.9	10.9
4	GA	COLUMBUS	49.0	14.9	14.9	7.6	10.2
4	GA	MACON	44.0	0.0	16.2	6.6	10.8
4	GA	SAVANNAH	52.0	20.7	16.7	6.2	10.9
4	GA	OTHER URBAN AREAS	46.5	13.2	15.1	7.6	10.8
4	GA	AVE. FOR STATE	46.5	13.2	15.1	7.6	10.8
4	KY	HUNTINGTON METRO	40.0	14.8	18.8	7.7	10.7
4	KY	LEXINGTON	44.0	0.0	15.4	7.3	12.8
4	KY	LOUISVILLE	41.0	19.1	19.1	5.5	12.2
4	KY	OWENSBORO	44.0	15.1	15.1	7.5	13.8
4	KY	OTHER URBAN AREAS	42.3	16.2	18.1	5.9	12.3
4	KY	AVE. FOR STATE	42.3	16.2	18.1	5.9	12.3
4	MS	BILOXI	58.0	0.0	14.8	7.6	10.1
4	MS	JACKSON	51.0	0.0	15.9	6.8	11.0
4	MS	OTHER URBAN AREAS	54.5	0.0	15.6	7.1	10.6
4	MS	AVE. FOR STATE	54.5	0.0	15.6	7.1	10.6
4	NC	ASHEVILLE	48.0	0.0	18.4	6.9	10.1
4	NC	CHARLOTTE	43.0	0.0	14.9	7.7	11.0
4	NC	DURHAM	43.0	0.0	13.7	8.9	10.6
4	NC	FAYETTEVILLE	47.0	0.0	15.0	7.5	10.4
4	NC	GREENSBORO	42.0	0.0	16.8	6.2	10.8
4	NC	HIGHPOINT	46.0	0.0	12.8	8.1	10.0
4	NC	RALEIGH	46.0	0.0	16.2	7.2	10.4
4	NC	WILMINGTON	52.0	0.0	18.9	4.8	10.2
4	NC	WINSTON-SALEM	47.0	0.0	15.0	7.5	10.8
4	NC	OTHER URBAN AREAS	46.0	0.0	15.5	7.3	10.5
4	NC	AVE. FOR STATE	46.0	0.0	15.5	7.3	10.5
4	SC	CHARLESTON	47.0	0.0	14.8	7.7	10.6
4	SC	COLUMBIA	47.0	0.0	15.4	7.5	10.6
4	SC	GREENVILLE	46.0	0.0	15.0	7.5	10.5
4	SC	OTHER URBAN AREAS	46.7	0.0	15.1	7.6	10.6
4	SC	AVE. FOR STATE	46.7	0.0	15.1	7.6	10.6
4	TN	CHATTANOOGA	54.0	15.6	15.6	6.8	10.1
4	TN	KNOXVILLE	46.0	0.0	15.3	7.6	10.5
4	TN	MEMPHIS	48.0	0.0	19.0	5.5	12.0
4	TN	NASHVILLE	45.0	16.5	13.2	5.5	9.4
4	TN	OTHER URBAN AREAS	48.3	16.3	17.0	6.0	10.6
4	TN	AVE. FOR STATE	48.3	16.3	17.0	6.0	10.6
4		AVE. FOR REGION 4	49.6	14.8	16.6	6.4	11.0

TABLE IV-4 ANNUAL DRY-WEATHER FLOW

EPA RFG	STATE ID	URBANIZED AREA	IN/YR ANNL PRECP	DRY-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
5	IL	AURORA	38.0	0.0	18.8	5.5	11.5
5	IL	BLOOMINGTON	36.0	0.0	18.0	6.0	12.1
5	IL	CHAMPAIGN	37.0	0.0	17.1	6.9	15.1
5	IL	CHICAGO	33.0	29.0	6.1	5.9	15.9
5	IL	DAVENPORT METRO	34.0	13.7	13.2	9.1	11.9
5	IL	DECATUR	37.0	11.1	0.0	11.1	11.1
5	IL	JOLIET	33.0	0.0	16.9	6.3	11.3
5	IL	PEORIA	35.0	10.4	0.0	10.6	10.6
5	IL	ROCKFORD	38.0	0.0	19.1	5.5	12.2
5	IL	SPRINGFIELD	35.0	15.2	15.2	7.4	12.2
5	IL	OTHER URBAN AREAS	35.0	26.8	9.7	6.4	14.6
5	IL	AVE. FOR STATE	35.0	26.8	9.7	6.4	14.6
5	IN	ANDERSON	36.0	5.4	0.0	0.0	5.4
5	IN	CHICAGO METRO	33.0	18.8	18.5	5.6	11.9
5	IN	EVANSVILLE	41.0	12.1	0.0	0.0	12.1
5	IN	FORT WAYNE	34.0	19.0	19.0	5.5	11.8
5	IN	INDIANAPOLIS	40.0	18.0	18.0	4.6	11.4
5	IN	LAFAYETTE	35.0	19.5	2.8	0.0	13.1
5	IN	MUNCIE	39.0	13.3	13.3	8.8	12.3
5	IN	SOUTH BEND	36.0	11.6	0.0	10.6	11.2
5	IN	TERRA HAUTE	41.0	0.0	13.9	9.2	10.9
5	IN	OTHER URBAN AREAS	37.2	14.8	16.8	5.8	11.0
5	IN	AVE. FOR STATE	37.2	14.8	16.8	5.8	11.0
5	MI	ANN ARBOR	31.0	0.0	15.1	7.4	12.8
5	MI	BAY CITY	28.0	11.5	0.0	11.5	11.4
5	MI	DETROIT	31.0	20.0	16.0	5.9	13.6
5	MI	FLINT	30.0	16.1	16.1	6.8	12.1
5	MI	GRAND RAPIDS	31.0	18.1	18.1	5.5	10.7
5	MI	JACKSON	34.0	11.8	0.0	9.3	10.4
5	MI	KALAMAZOO	34.0	0.0	16.8	6.3	10.3
5	MI	LANSING	31.0	15.9	15.9	6.9	11.7
5	MI	MUSKEGON	32.0	0.0	17.0	5.6	10.2
5	MI	SAGINAW	28.0	12.0	0.0	12.0	12.0
5	MI	OTHER URBAN AREAS	31.0	18.9	16.2	6.3	12.9
5	MI	AVE. FOR STATE	31.0	18.9	16.2	6.3	12.9
5	MN	DULUTH	29.0	16.3	16.3	5.8	9.6
5	MN	FARGO METRO	21.0	13.3	13.3	8.8	12.2
5	MN	MINNEAPOLIS	25.0	16.9	16.9	5.5	10.6
5	MN	ROCHESTER	29.0	0.0	18.1	8.1	12.6
5	MN	OTHER URBAN AREAS	26.0	16.6	16.7	5.6	10.6
5	MN	AVE. FOR STATE	26.0	16.6	16.7	5.6	10.6
5	OH	AKRON	38.0	0.0	18.3	5.5	11.0
5	OH	CANTON	38.0	20.9	18.7	5.5	11.7
5	OH	CINCINNATI	38.0	18.2	18.2	8.1	11.9
5	OH	CLEVELAND	32.0	22.8	22.8	3.7	11.5
5	OH	COLUMBUS	36.0	21.2	21.2	4.8	12.0
5	OH	DAYTON	35.0	0.0	17.8	5.9	11.8
5	OH	HAMILTON	40.0	19.8	19.8	4.7	10.7
5	OH	LIMA	36.0	9.3	0.0	0.0	9.3
5	OH	LORAIN	35.0	67.2	16.5	5.6	10.0
5	OH	MANSFIELD	43.0	0.0	13.1	9.0	10.1
5	OH	SPRINGFIELD	40.0	13.2	13.2	8.8	10.5
5	OH	STEUBENVILLE	40.0	14.0	0.0	0.0	12.4
5	OH	TOLEDO	32.0	17.3	16.0	6.4	11.4
5	OH	YOUNGSTOWN	42.0	16.8	16.8	6.4	11.6
5	OH	OTHER URBAN AREAS	37.2	16.8	19.4	5.3	11.5
5	OH	AVE. FOR STATE	37.2	16.8	19.4	5.3	11.5
5	WI	APPLETON	29.0	19.3	19.3	5.5	12.2
5	WI	DULUTH METRO	29.0	0.0	10.1	6.0	8.8
5	WI	GREEN BAY	27.0	14.4	14.4	7.7	9.8
5	WI	KENOSHA	32.0	18.7	12.8	0.0	13.8
5	WI	LA CROSSE	31.0	15.0	15.0	7.6	11.0
5	WI	MADISON	31.0	0.0	18.2	5.2	11.4
5	WI	MILWAUKEE	28.0	31.6	8.7	8.2	11.1
5	WI	OSHKOSH	28.0	0.0	13.2	0.0	13.2
5	WI	RACINE	32.0	0.0	15.1	7.2	13.1
5	WI	OTHER URBAN AREAS	29.7	28.7	11.8	7.6	11.3
5	WI	AVE. FOR STATE	29.7	28.7	11.8	7.6	11.3
5		AVE. FOR REGION 5.	32.7	20.4	14.9	6.0	12.4

TABLE IV-4 ANNUAL DRY-WEATHER FLOW

EPA RFG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	DRY-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
6	AR	FORT SMITH	43.0	9.3	0.0	9.3	9.3
6	AR	LITTLE ROCK	49.0	0.0	15.9	8.7	10.6
6	AR	PINE BLUFF	52.0	0.0	14.4	8.1	11.3
6	AR	OTHER URBAN AREAS	48.0	9.3	15.4	8.8	10.4
6	AR	AVE. FOR STATE	48.0	9.3	15.4	8.8	10.4
6	LA	BATON ROUGE	60.0	0.0	16.2	6.8	11.4
6	LA	LAFAYETTE	59.0	0.0	14.3	8.1	11.6
6	LA	LAKE CHARLES	58.0	0.0	14.9	7.6	10.9
6	LA	MONROE	50.0	0.0	13.9	8.8	10.5
6	LA	NEW ORLEANS	64.0	0.0	25.3	0.0	25.3
6	LA	SHREVEPORT	45.0	0.0	14.5	7.7	10.8
6	LA	OTHER URBAN AREAS	56.0	0.0	20.8	7.6	16.2
6	LA	AVE. FOR STATE	56.0	0.0	20.8	7.6	16.2
6	NM	ALBUQUERQUE	9.0	0.0	17.0	6.2	11.0
6	NM	OTHER URBAN AREAS	9.0	0.0	17.0	6.2	11.0
6	NM	AVE. FOR STATE	9.0	0.0	17.0	6.2	11.0
6	OK	LAWTON	30.0	0.0	13.6	9.0	10.4
6	OK	OKLAHOMA CITY	31.0	0.0	18.4	4.8	9.8
6	OK	TULSA	37.0	0.0	17.3	5.6	10.3
6	OK	OTHER URBAN AREAS	32.7	0.0	17.6	5.5	10.0
6	OK	AVE. FOR STATE	32.7	0.0	17.6	5.5	10.0
6	TX	ABILENE	24.0	0.0	16.4	5.0	9.2
6	TX	AMARILLO	20.0	0.0	17.5	5.6	10.5
6	TX	AUSTIN	33.0	0.0	15.9	6.9	11.6
6	TX	BEAUMONT	54.0	17.8	17.8	4.8	9.6
6	TX	BROWNSVILLE	27.0	0.0	13.4	8.8	12.2
6	TX	BRYAN	39.0	0.0	17.8	4.8	9.8
6	TX	CORPUS CHRISTI	28.0	0.0	18.1	4.8	9.8
6	TX	DALLAS	35.0	0.0	18.3	4.3	10.2
6	TX	EL PASO	8.0	0.0	18.6	5.2	11.2
6	TX	FORT WORTH	30.0	0.0	18.4	4.8	9.8
6	TX	GALVESTON	43.0	48.9	0.0	7.4	11.1
6	TX	HARLINGEN	26.0	0.0	10.9	9.3	9.6
6	TX	HOUSTON	46.0	33.6	14.9	7.6	11.6
6	TX	LAREDO	19.0	0.0	14.3	8.1	11.7
6	TX	LUBBOCK	18.0	0.0	14.8	7.6	10.1
6	TX	MCALLEN	21.0	0.0	13.4	9.1	11.2
6	TX	MIDLAND	14.0	0.0	13.0	9.1	10.0
6	TX	ODESSA	14.0	0.0	14.5	8.1	11.8
6	TX	PORT ARTHUR	54.0	0.0	14.3	7.8	9.7
6	TX	SAN ANGELO	19.0	0.0	13.1	9.1	10.0
6	TX	SAN ANTONIO	28.0	0.0	19.1	5.5	12.1
6	TX	SHERMAN	39.0	0.0	11.7	9.2	9.7
6	TX	TEXARKANA	46.0	0.0	13.0	9.1	10.0
6	TX	TEXAS CITY	45.0	0.0	15.2	5.6	9.0
6	TX	TYLER	45.0	0.0	15.0	7.6	10.7
6	TX	WACO	32.0	0.0	16.7	5.2	9.4
6	TX	WICHITA FALL	29.0	0.0	13.7	8.9	10.6
6	TX	OTHER URBAN AREAS	31.0	26.6	16.6	6.0	10.7
6	TX	AVE. FOR STATE	31.0	26.6	16.6	6.0	10.7
6		AVE. FOR REGION 6.	35.3	14.6	17.4	6.3	11.2

TABLE IV-4 ANNUAL DRY-WEATHER FLOW

EPA RFG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	DRY-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
7	IA	CEDAR RAPIDS	33.0	0.0	15.0	7.5	10.4
7	IA	DAVENPORT	34.0	16.0	16.0	5.9	9.4
7	IA	DES MOINES	31.0	39.5	7.9	5.8	10.6
7	IA	DUBUQUE	33.0	0.0	13.4	8.8	12.0
7	IA	SIOUX CITY	25.0	0.0	17.6	5.1	9.7
7	IA	WATERLOO	32.0	0.0	14.4	7.7	9.7
7	IA	OTHER URBAN AREAS	31.3	38.1	13.2	6.5	10.2
7	IA	AVE. FOR STATE	31.3	38.1	13.2	6.5	10.2
7	KS	KANSAS CITY METRO	34.0	15.9	15.9	6.9	11.7
7	KS	TOPEKA	34.0	16.3	16.3	6.6	10.8
7	KS	WICHITA	31.0	0.0	15.0	7.5	11.3
7	KS	OTHER URBAN AREAS	33.0	16.0	15.5	7.1	11.4
7	KS	AVE. FOR STATE	33.0	16.0	15.5	7.1	11.4
7	MO	COLUMBIA	37.0	0.0	17.0	5.2	9.5
7	MO	KANSAS CITY	34.0	19.7	8.9	7.7	10.2
7	MO	SPRINGFIELD	41.0	0.0	16.2	6.3	10.1
7	MO	ST.JOSEPH	35.0	7.2	0.0	0.0	7.2
7	MO	ST.LOUIS	37.0	13.1	0.0	12.8	13.0
7	MO	OTHER URBAN AREAS	36.8	13.4	11.4	10.1	11.6
7	MO	AVE. FOR STATE	36.8	13.4	11.4	10.1	11.6
7	NE	LINCOLN	27.0	0.0	17.4	6.2	11.4
7	NE	OMAHA	26.0	19.0	19.0	5.5	11.8
7	NE	OTHER URBAN AREAS	26.5	19.0	18.0	5.6	11.7
7	NE	AVE. FOR STATE	26.5	19.0	18.0	5.6	11.7
7		AVE. FOR REGION .7	31.9	15.4	14.2	8.0	11.2
8	CO	BOULDER	19.0	0.0	17.4	6.6	14.2
8	CO	COLORADO SPRINGS	13.0	0.0	15.1	7.5	10.5
8	CO	DENVER	14.0	35.4	18.1	5.8	12.2
8	CO	PUEBLO	12.0	24.6	12.8	7.6	11.8
8	CO	OTHER URBAN AREAS	14.5	26.8	17.3	6.3	12.0
8	CO	AVE. FOR STATE	14.5	26.8	17.3	6.3	12.0
8	MT	BILLINGS	13.0	0.0	15.0	7.6	11.0
8	MT	GREAT FALLS	15.0	0.0	13.6	8.4	11.8
8	MT	OTHER URBAN AREAS	14.0	0.0	14.2	7.9	11.4
8	MT	AVE. FOR STATE	14.0	0.0	14.2	7.9	11.4
8	ND	FARGO	21.0	14.3	14.3	8.3	12.2
8	ND	OTHER URBAN AREAS	21.0	14.3	14.3	8.3	12.2
8	ND	AVE. FOR STATE	21.0	14.3	14.3	8.3	12.2
8	SD	SIOUX FALLS	25.0	16.4	16.4	7.1	11.2
8	SD	OTHER URBAN AREAS	25.0	16.4	16.4	7.1	11.2
8	SD	AVE. FOR STATE	25.0	16.4	16.4	7.1	11.2
8	UT	OGDEN	17.0	0.0	16.5	6.2	10.8
8	UT	PROVO	13.0	0.0	17.6	5.1	9.7
8	UT	SALT LAKE CITY	15.0	0.0	17.1	6.0	11.0
8	UT	OTHER URBAN AREAS	15.0	0.0	17.1	5.9	10.7
8	UT	AVE. FOR STATE	15.0	0.0	17.1	5.9	10.7
8	WY	URBAN AREAS	15.0	0.0	15.0	7.6	11.0
8	WY	AVE. FOR STATE	15.0	0.0	15.0	7.6	11.0
8		AVE. FOR REGION 8.	17.4	21.4	16.4	6.6	11.5

TABLE IV-4 ANNUAL DRY-WEATHER FLOW

EPA RFG	STATE ID	URBANIZED AREA	TN/YR ANNL. PRECP	DRY-WEATHER FLOW (INCHES PER YEAR) COMB	STORM	UNSEW	AVER
9	AK	URBAN AREAS	30.0	18.5	18.5	4.9	10.1
9	AK	AVE. FOR STATE	30.0	18.5	18.5	4.9	10.1
9	AZ	PHOENIX	7.0	0.0	16.8	5.3	10.5
9	AZ	TUCSON	11.0	0.0	15.5	7.4	11.2
9	AZ	OTHER URBAN AREAS	9.0	0.0	16.5	5.8	10.6
9	AZ	AVE. FOR STATE	9.0	0.0	16.5	5.8	10.6
9	CA	BAKERSFIELD	11.0	0.0	17.8	5.9	11.6
9	CA	FRESNO	11.0	0.0	15.9	6.9	11.9
9	CA	LOS ANGELES	13.0	0.0	17.1	6.8	14.8
9	CA	MODESTO	25.0	0.0	14.9	7.6	11.6
9	CA	OXNARD	15.0	0.0	17.7	5.5	10.4
9	CA	SACRAMENTO	18.0	16.8	16.8	6.1	10.9
9	CA	SALINAS	15.0	0.0	15.1	7.5	13.0
9	CA	SAN BERNANDINO	18.0	0.0	18.9	4.7	10.0
9	CA	SAN DIEGO	11.0	0.0	17.6	6.0	11.7
9	CA	SAN FRANCISCO	21.0	35.0	18.2	4.0	13.4
9	CA	SAN JOSE	14.0	0.0	19.2	5.6	12.4
9	CA	SANTA BARBARA	18.0	0.0	15.2	7.4	12.2
9	CA	SANTA ROSA	30.0	0.0	13.3	9.0	10.2
9	CA	SEASIDE	16.0	0.0	13.2	8.8	12.7
9	CA	SIMI VALLEY	25.0	0.0	14.9	7.7	10.5
9	CA	STOCKTON	14.0	0.0	15.2	7.4	12.0
9	CA	OTHER URBAN AREAS	17.2	33.3	17.3	5.7	13.4
9	CA	AVE. FOR STATE	17.2	33.3	17.3	5.7	13.4
9	HI	HONOLULU	23.0	0.0	18.2	6.0	12.6
9	HI	OTHER URBAN AREAS	23.0	0.0	18.2	6.0	12.6
9	HI	AVE. FOR STATE	23.0	0.0	18.2	6.0	12.6
9	NV	LAS VEGAS	4.0	0.0	17.3	5.6	10.1
9	NV	RENO	7.0	19.3	14.3	7.1	11.0
9	NV	OTHER URBAN AREAS	5.5	19.3	16.8	6.0	10.4
9	NV	AVE. FOR STATE	5.5	19.3	16.8	6.0	10.4
9		AVE. FOR REGION 9	16.9	32.6	17.2	5.7	13.0
10	ID	BOISE	11.0	0.0	14.2	8.8	11.4
10	ID	OTHER URBAN AREAS	11.0	0.0	14.2	8.8	11.4
10	ID	AVE. FOR STATE	11.0	0.0	14.2	8.8	11.4
10	OR	EUGENE	38.0	16.2	16.2	6.6	10.9
10	OR	PORTLAND	40.0	17.6	17.6	6.0	11.6
10	OR	SALEM	40.0	0.0	14.9	7.6	10.8
10	OR	OTHER URBAN AREAS	39.3	17.5	16.9	6.2	11.4
10	OR	AVE. FOR STATE	39.3	17.5	16.9	6.2	11.4
10	WA	SEATTLE	35.0	17.1	17.1	6.1	11.5
10	WA	SPOKANE	17.0	11.4	0.0	11.4	11.4
10	WA	TACOMA	39.0	16.8	16.8	6.3	10.9
10	WA	OTHER URBAN AREAS	30.3	15.2	17.0	6.5	11.4
10	WA	AVE. FOR STATE	30.3	15.2	17.0	6.5	11.4
10		AVE. FOR REGION 10	26.9	15.9	16.5	6.6	11.4
		AVERAGE FOR THE U.S.	33.4	22.5	17.5	6.2	12.8

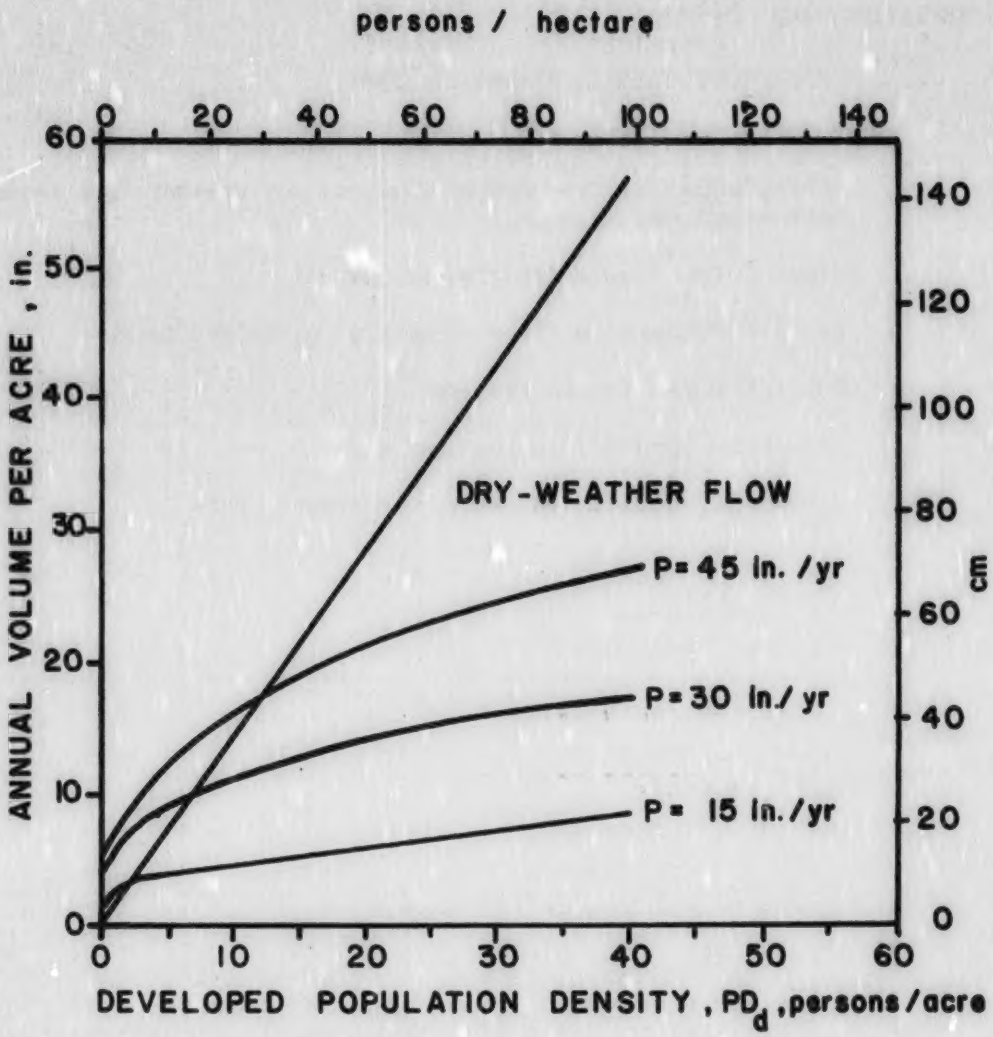

Figure IV-4. Comparative Magnitude of Annual Wet- and Dry-Weather Flows

ABBREVIATIONS AND SYMBOLS

AR	Wet-weather runoff, inches per year
CR	Runoff coefficient
DWF	Abbreviation for dry-weather flow and dry-weather flow runoff, inches per year
I	Imperviousness as a fraction or percent
I_a	Initial abstraction (loss) from precipitation, inches
P	Precipitation, inches per year
PD	Population density, persons per acre
PD_d	Developed population density, persons per acre

REFERENCES

1. Bowers, C. E., Harris, G. S. and Pabst, A. F., "The Real-Time Computation of Runoff and Storm Flow in the Minneapolis-St. Paul Interceptor Sewers," St. Anthony Falls Hydraulic Laboratory, Memo No. M-118, University of Minnesota, Minneapolis, December 1968.

2. Leiser, C. P., "Computer Management of a Combined Sewer System," Office of Research and Development, USEPA Report EPA-670/2-74-022, NTIS-PB 235 717, July 1974.

3. Brandstetter, A. B., "An Assessment of Mathematical Models for Storm and Combined Sewer Management," USEPA Report EPA-600/2-76-175a, 1975.

4. Huber, W. C., "Modeling for Storm Water Strategies," APWA Reporter, Vol. 42, No. 5, pp. 10-14, May 1975.

5. DiGiano, F. A. and Mangarella, P. A., eds., "Application of Stormwater Management Models," USEPA Report EPA-670/2-75-065, NTIS-PB 247 163, June 1975.

6. American Society of Civil Engineers, "Urban Hydrology Research," Report, Engineering Foundation Research Conference, Andover, New Hampshire, ASCE Urban Hydrology Research Council, August 1975.

7. McPherson, M. B. and Schneider, W. J., "Problems in Modeling Urban Watersheds," Water Resources Research, Vol. 10, No. 3, pp. 434-440, June 1974.

8. Hydrologic Engineering Center, Corps of Engineers, "Urban Storm Water Runoff: STORM," Generalized Computer Program 723-58-L2520, May 1975.

9. Roesner, L. A., et al., "A Model for Evaluating Runoff-Quality in Metropolitan Master Planning," ASCE Urban Water Resources Research Program, Technical Memo No. 23, ASCE, 345 E 47 St., NY, NY 10017, 72 pp., April 1974.

10. Smith, G. F., "Adaptation of the EPA Storm Water Management Model for Use in Preliminary Planning for Control of Urban Storm Runoff," MS Thesis, Department of Environmental Engineering Sciences, University of Florida, Gainesville, May 1975.

11. Metcalf and Eddy, Inc., University of Florida and Water Resources Engineers, Inc., "Storm Water Management Model, Volume I - Final Report," USEPA Report 11024DOC07/71, NTIS-PB 203 289, September 1971.

12. Metcalf and Eddy, Inc., University of Florida and Water Resources Engineers, Inc., "Storm Water Management Model, Volume II - Verification and Testing," USEPA Report 11024DOC08/71, NTIS-PB 203 290, September 1971.

13. Metcalf and Eddy, Inc., University of Florida and Water Resources Engineers, Inc., "Storm Water Management Model, Volume III - User's Manual," USEPA Report 11024DOC09/71, NTIS-PB 203 291, September 1971.

14. Metcalf and Eddy, Inc., University of Florida and Water Resources Engineers, Inc., "Storm Water Management Model, Volume IV - Program Listing," USEPA Report 11024DOC10/71, NTIS-PB 203 292, September 1971.

15. Heaney, J. P., Huber, W. C., *et al.*, "Urban Stormwater Management Modeling and Decision-Making," USEPA Report EPA-670/2-75-022, NTIS-PB 242 290, March 1975.

16. Huber, W. C., Heaney, J. P., *et al.*, "Storm Water Management Model User's Manual Version II," USEPA Report EPA-670/2-75-017, March 1975.

17. Miller, C. R. and Viessman, W., Jr., "Runoff Volumes from Small Urban Watersheds," Water Resources Research, Vol. 8, No. 2, pp. 429-434, April 1972.

18. Graham, P. H., Costello, L. S. and Mallon, H. J., "Estimation of Imperviousness and Specific Curb Length for Forecasting Stormwater Quality and Quantity," JWPCF, Vol. 46, No. 4, pp. 717-725, April 1974.

19. Stankowski, S. J., "Magnitude and Frequency of Floods in New Jersey with Effects of Urbanization," Special Report 38, US Geological Survey, Water Resources Division, Trenton, NJ, 1974.

20. American Public Works Association and University of Florida, "Evaluation of the Magnitude and Significance of Pollution Loading from Urban Stormwater Runoff - Ontario," Environmental Protection Service and Ontario Ministry of Environment, Toronto, 1976.

21. Climates of the States, Water Information Center, Inc., Port Washington, NY, 1974.

SECTION V

QUALITY ANALYSIS

Quality analyses may be performed at several levels of detail, ranging from an explicit formulation of runoff quality for small subcatchments within a city to a broad representation of pollutant loads for an entire urbanized area, state or region. It has been necessary to consider the entire spectrum during the course of this research.

It is unfortunate that perhaps the only consistent remark about urban runoff quality analysis in general is that data and results of previous studies are so remarkably inconsistent. As discussed in Volume III of this report, few studies have been made of characteristics of street litter, and they offer a wide range of values of concentrations and loads. Effluent data show a similar scatter. However, it is necessary that a decision be made regarding actual values for use in the analysis. This section will describe methods used for predicting runoff quality, data required for their use, and final results used in this study.

QUALITY PARAMETERS

Parameter Definitions

Urban runoff quality may be characterized by a variety of parameters, as documented in Volume III. However, the list is generally shortened for modeling purposes to those characteristic of solids, oxygen demand, health hazards and aquatic growth potential, as indicated in Table V-1, Typical Quality Parameters of Urban Runoff Models. It is discouraging that even at this juncture, a serious problem of definition of terms arises because of various possibilities for analyzing and reporting quality parameters. The assurance that analyses have been performed according to Standard Methods[1] is not enough information. For example, solids are sometimes reported as "residue" instead of solids, and "filterable residue" instead of "dissolved solids," because of the nature of the evaporation and filtration techniques utilized in the chemical analyses. Generally, "solids" and "residue" are synonymous, and "solids" will be used in this report. Another problem arises from the fact that pollutants may be in both soluble and insoluble forms. Some studies report concentrations of only the soluble portions of, say, BOD and PO_4, leading to unrealistically low values if the reader mistakenly thinks of them as total (soluble plus insoluble) concentrations.

TABLE V-1. TYPICAL QUALITY PARAMETERS OF URBAN RUNOFF MODELS

Quality Characteristic	Representative Quality Parameters
Solids	Surface "Dust and Dirt"
	Surface "Solids"
	Total Solids
	Suspended Solids
	Dissolved Solids
	Volatile Solids
	Settleable Solids
Oxygen Demand	BOD, COD
	Total Organic Carbon
	Organic N, NO_2, NH_3
Health Hazards	Total Coliforms
	Fecal Coliforms
Aquatic Growth Potential	Ortho-PO_4
	Total PO_4
	NO_2, NO_3, Total N

On the other hand, it is important to know the relative soluble-insoluble fractions of pollutants since this has a major impact upon treatability. That is, pollutants that appear as suspended solids are relatively easy to remove (e.g., by sedimentation) compared to those that are soluble.

To further complicate the picture, no clear relationship exists between data derived from studies of surface litter (gathered by sweeping, vacuuming, flushing) and those resulting from analysis of the runoff itself (e.g., samples of storm and combined sewage effluent sources). There is no study in which samples of both types have been gathered simultaneously. Hence, the relationship between the two is not well defined, and it is difficult to draw conclusions from all data considered together.

In this report, the solids relationship of Figure V-1, Relationships Among Solids Parameters, applies. Note that total solids (TS) is the sum of dissolved solids (DS) plus suspended solids (SS), and that total, dissolved and suspended solids may be separated into a volatile portion (generally considered the organic portion) and a fixed portion. Volatile solids (VS) will refer to a portion of total solids in this report, unless otherwise indicated. Settleable solids are some fraction of suspended solids. Note, finally, that an upper limit on the size of total solids reported is imposed by the size of the openings in the sampling equipment (e.g., a quarter-inch mesh screen).

Similar diagrams may be prepared for nitrogen and phosphorus, as shown in Figure V-2, Relationships Among Nitrogen Parameters, and Figure V-3, Relationships Among Phosphorus Parameters. For these parameters it is necessary to know whether concentrations are being reported of the element itself (e.g., phosphorus) or the ion (e.g., PO_4), although conversions can readily be made on the basis of the molecular weight of each. Regarding the nitrogen relationships, all concentrations should be reported in terms of N (i.e., NO_2-N, NO_3-N, NH_3-N) in order for mass balances to be performed easily.

Parameters for Assessment

For purposes of the nationwide assessment, five parameters will be used that are representative to some degree of the quality characteristics indicated in Table V-1. These are indicated in Table V-2, Quality Parameters Used in Nationwide Assessment.

Five-day BOD is used because of its broad acceptance and traditional role in water quality analysis. Its usefulness is severely impaired by the great difficulty in performing accurate and consistent laboratory analyses. For instance, there is no standard for laboratory comparison, and low-level values (e.g., 10 mg/l) are especially susceptible to errors of up to 100 percent. Moreover, studies have shown that results

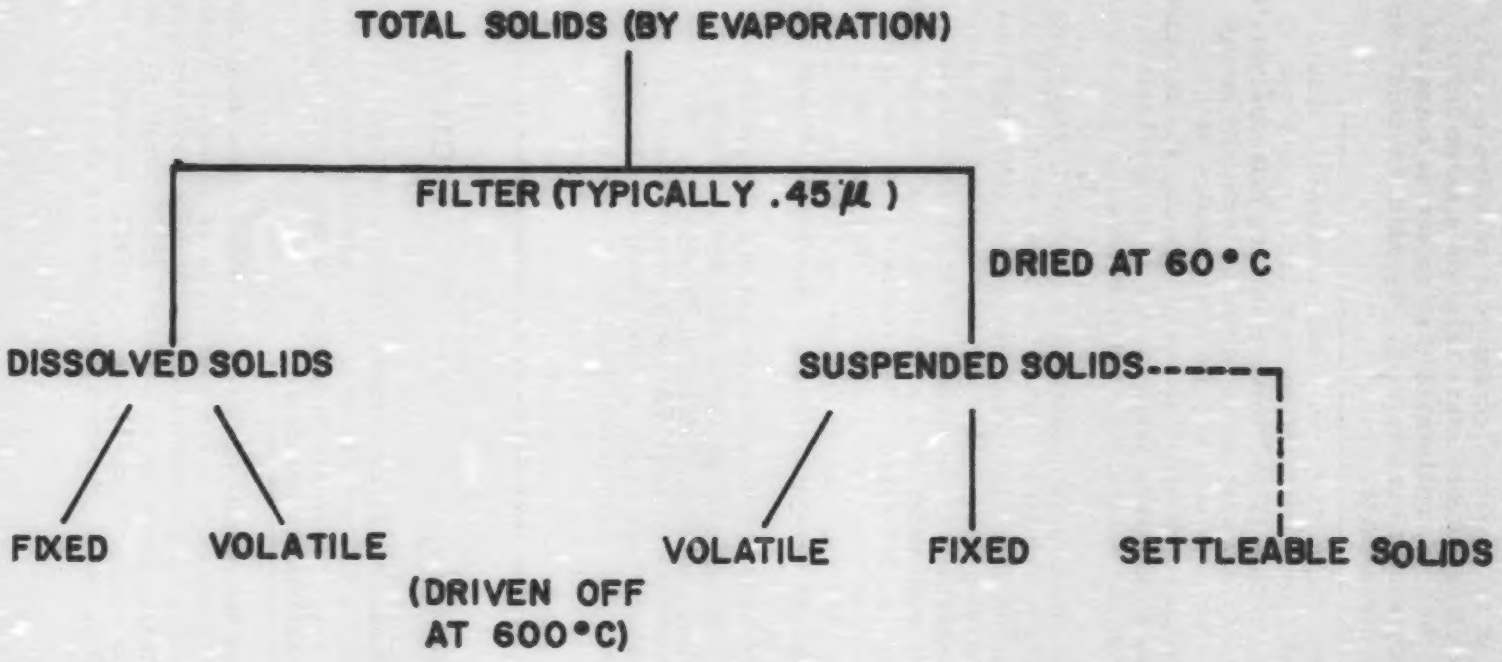
TOTAL SOLIDS (BY EVAPORATION)
FILTER (TYPICALLY .45 μ)
DRIED AT 60° C
DISSOLVED SOLIDS
SUSPENDED SOLIDS
FIXED
VOLATILE
VOLATILE
FIXED
SETTLEABLE SOLIDS
(DRIVEN OFF
AT 600°C)

Figure V-1. Relationships Among Solids Parameters

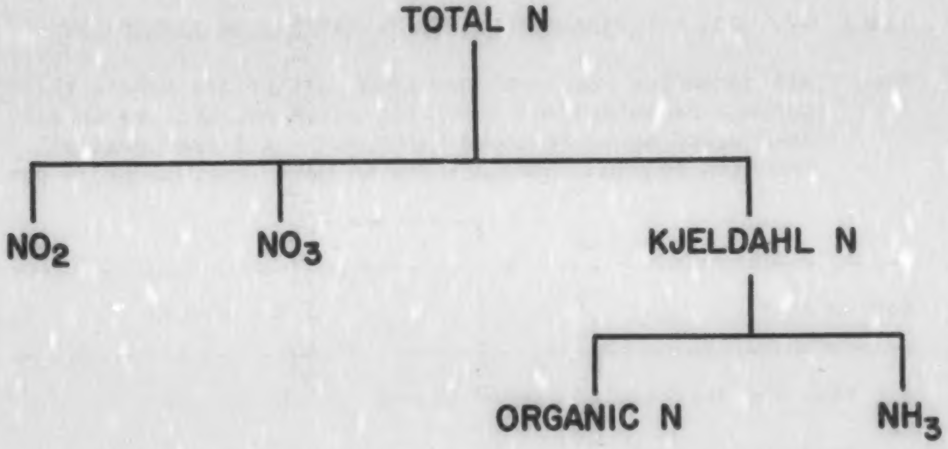
TOTAL N
NO2
NO3
KJELDAHL N
ORGANIC N
NH3

Figure V-2. Relationships Among Nitrogen Parameters.

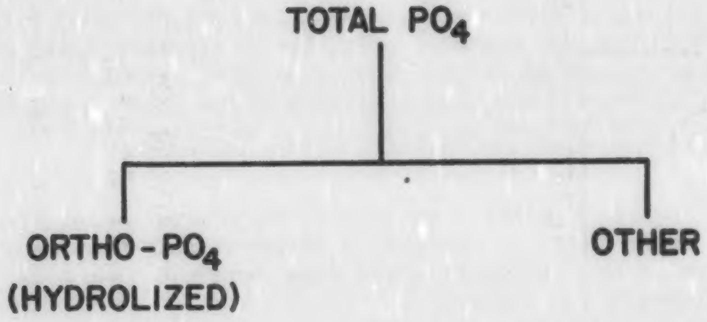
TOTAL PO4
ORTHO-PO4
(HYDROLIZED)
OTHER

Figure V-3. Relationships Among Phosphorus Parameters.

TABLE V-2. QUALITY PARAMETERS USED IN NATIONWIDZ ASSESSMENT

Note: All parameters (except suspended solids) are totals that include dissolved and insoluble portions, and are usually determined as in Standard Methods.[1] All are usually reported in concentration units of mg/l (equivalent to ppm).

Parameter	Abbreviation
1. Five-Day Biochemical Oxygen Demand	BOD_5 or BOD
2. Suspended Solids	SS
3. Volatile Solids (Total)	VS
4. Total Phosphate (as PO_4)	PO_4 or TPO_4
5. Total Nitrogen (as N)	N

are affected by the percent dilution and are generally not reproducible.[2] In addition, samples are affected by amounts of heavy metals and other parameters present. Use of COD and/or TOC avoids these problems for the most part, but their relationship with traditional stream sanitation analysis (i.e., prediction of dissolved oxygen) is unclear, and most people are used to thinking in terms of BOD. It is used in this study, realizing its limitations.

The other four parameters are used because of general acceptance and availability of data. It should be borne in mind that many options are available for modeling purposes, and the choice of parameters is somewhat arbitrary.

PREDICTIVE TECHNIQUES

Pollutant loads

The quality prediction techniques found in most urban runoff models (e.g., SWMM, STORM) rely upon generation of an initial surface load of pollutants. This load is usually expressed in units of lbs, lbs/acre, lbs/curb-mile, lbs/day-acre, or lbs/day-curb-mile (or equivalent metric units). Normalized loads are, of course, multiplied by a unit of area, dry days, etc., to produce an initial mass of pollutants at the start of the storm. Pollutants are then "washed off" during the storm in an exponential fashion, in which the amount removed per time step is proportional to the amount present, the runoff rate, and other factors. See SWMM[3,4] and STORM[5,6] documentation for details of this methodology. The key factor in prediction of long-term (e.g., annual) pollutant loads from urban areas is, however, the surface loading rates themselves, and most of the following discussion will be devoted to them.

Surface loadings are usually predicted by one of two means: estimates based on surface accumulation data or estimates based on measurements of effluent concentrations and flows. As mentioned earlier, no one study has performed the analysis both ways, so comparisons are not easily accomplished. However, to attain the objective of this analysis, normalization of loading rates by some means that could be converted to total mass of pollutants upon multiplication by area, days and/or other appropriate parameters was necessary. As a result, both methods were utilized in the development that follows.

Surface Accumulation Methods

Both SWMM and STORM use this method for prediction of the total soluble mass of pollutants available at the beginning of a storm. It is based upon the following equation, given in US customary units

$$P_{i,j} = dd_i \cdot F_{i,j} \cdot G_{L,i} \cdot A_i \cdot N_D + P_o \qquad \text{(V-1)}$$

where $P_{i,j}$ = total soluble pounds of pollutant j on urban land use i at the beginning of the storm,

dd_i = pounds of accumulated dust and dirt on land use i (or "surface solids") per curb-mile per dry day,

$F_{i,j}$ = soluble pounds of pollutant j per pound of dust and dirt found on land use i,

$G_{L,i}$ = curb-miles per acre of land use i,

A_i = area of land use i, acres,

N_D = number of dry days since last storm, and

P_o = total soluble pounds of pollutant remaining on land use i at end of last storm.

The dust and dirt accumulation rate is often given in terms of pounds per day per 100 ft of curb instead of curb-miles, but the latter units are used here for ease in comparison with other portions of the report.

The parameter N_D is the number of dry days since the last storm, not the number of days since the last storm or street cleaning operation. This is due to the fact that, in most cases, the interarrival time between storms is less than the street cleaning interval. The latter generally ranges from one to two days to several months. Allowance for street sweeping is incorporated later in the report.

The parameters dd_i, $F_{i,j}$ and $G_{L,i}$ are functions of land use, i. The dust and dirt loadings, dd_i, and pollutant fractions, $F_{i,j}$, are usually based for the most part on the 1969 APWA Chicago data[7] and are shown in Table V-3, Parameters for Surface Pollutant Accumulation Used in SWMM and/or STORM. The extensive efforts documented in Volume III of this report allow the updating of all parameters of this table, as will be described subsequently.

The insoluble portion of pollutants is accounted for (in STORM and SWMM) by addition of a fraction of the solids concentration to predicted effluent concentration (of the soluble portion). For example, SWMM adds five percent of the SS concentration to the soluble BOD concentration to obtain total BOD, on the basis of calibration of the original SWMM in San Francisco. This is because of the reliance upon the 1969 APWA Chicago data in which only soluble fractions were reported. It is obvious that equation V-1 could be used to predict the total (soluble plus insoluble) mass of surface pollutant accumulation simply by a redefinition of terms (and use of appropriate revised numbers). This would facilitate quality calibration of the models and probably be as accurate considering the available data. Final surface pollutant loads derived subsequently will refer to total pounds of pollutants. The data presented in Volume III will be utilized subsequently to revise the dust and dirt loadings and pollutant fractions.

Starting with the Chicago study and followed subsequently by others, it has become customary to report data in terms of mass of pollutants per unit length of curb, under the assumption that the curbs and gutters represent the main source area for acquisition of pollutants by the storm runoff. In order to obtain loadings on a unit area basis, it is necessary to obtain the length of curb per area for each land use, thus defining the parameter G_L in equation V-1.

It is expected that G_L would be a function of land use, which in turn is a function of population density, PD. Curb length (taken as twice street length) was related to population density in the Washington, DC area by Graham et al.[8] Their data were augmented by data from other parts of the country as described in Volume III, resulting in

$$G_L = 0.0782 - 0.0668 \cdot 0.839^{PD_d} \qquad \text{(V-2)}$$

where G_L = curb-miles per area, mile/acre, and

PD_d = developed population density, persons/acre.

Table V-3. PARAMETERS FOR SURFACE POLLUTANT ACCUMULATION USED IN SWMM AND/OR STORM

Except as noted, values are for soluble portion and derived from the 1969 APWA Chicago study.[7]

		Land Use				
Parameter	Units	1. Single-family res.	2. Multi-family res.	3. Commercial	4. Industrial	5. Open[a]
Dust and dirt loading, dd_i	lb/day-curb-mile	40.0	121.0	174.0	243.0	79.2
	kg/day-curb-km	11.4	34.4	49.4	69.0	22.5
Pollutant fractions[b], $F_{i,j}$						
SS[a] (SWMM)		1.0	1.0	1.0	1.0	1.0
SS[a] (STORM)		0.111	0.08	0.17	0.067	0.111
Settleable Solids[c] (SWMM)		0.1	0.1	0.1	0.1	0.1
Settleable Solids[c] (STORM)		0.011	0.008	0.017	0.007	0.011
BOD_5		0.005	0.0036	0.0077	0.003	0.005
COD		0.04	0.04	0.039	0.04	0.02
Total PO_4		0.00005	0.00005	0.00007	0.00003	0.00001
Total N		0.00048	0.00061	0.00041	0.00043	0.00005
Grease[a]		0.001	0.001	0.001	0.001	0.001
Total Coliforms	MPN/g	1.3×10^6	2.7×10^6	1.7×10^6	1.0×10^6	0.00

[a] All values assumed.

[b] Fraction refers only to soluble fraction of dust and dirt (except for solids).

[c] All values assumed at 10% of value for SS.

Equation V-2 seems to work well for residential areas, but the curb length concept is troublesome when one is evaluating commercial, industrial or open areas. For example, what is the equivalent curb length of a shopping center? Data from other sources are compared in Table V-4, Measured Curb Lengths for Various Land Uses. An average of the Tulsa[9] and Ontario[23] data is used in the analysis. Specific data for residential areas are used in lieu of equation V-2, since the equation was developed to predict curb length as a function of population density averaged over all land uses. However, the equation may be used when considering an overall urban area.

To summarize, the surface accumulation methods are convenient for modeling purposes and illustrate the linkages between various causative factors. The key missing factor is a link between the surface loads and effluent loads that has been verified by measurements of both. Until this is accomplished, such a link must be hypothesized in its mathematical formulation, as done in SWMM and STORM. However, equation V-1 is used in developments that follow to relate loadings between different land uses and pollutants; hence, the reason for the previous developments. The other side of the coin, that is, results derivable from effluent data alone, will be discussed next.

Effluent Concentration Methods

Many studies in recent years have reported measured concentrations of pollutants in storm and combined sewer discharges. If the flow rate is also known, the mass flow pollutograph may be determined (e.g., lbs/min of BOD) and integrated to produce the total mass emission for the storm discharge. When distributed over the area of the catchment and divided by the number of preceding dry days, normalized loadings (e.g., mass-BOD/area-day) may be determined. Some studies report these values directly, while others report a lesser amount of information. In general, the surface loading may be deduced from a measured average concentration and assumed runoff quantity:

$$M = P \cdot C \cdot CR \cdot \rho \qquad \text{(V-3)}$$

where M = pollutant loading, mass/area-time,

P = precipitation, depth/time,

C = average concentration = mass of pollutant per mass of total sample,

CR = runoff coefficient, and

ρ = water density, mass/volume.

For an individual storm, preceded by N_D dry days, the total depth of precipitation, P_s, may be given. Then,

Table V-4. MEASURED CURB LENGTHS FOR VARIOUS LAND USES

	Location								
	Tulsa[9]			10 Ontario Cities[a]			Average of Two Locations for Use in Study		
	mile/acre	km/ha	100ft/acre	mile/acre	km/ha	100ft/acre	mile/acre	km/ha	100 ft/acre
Residential	0.076	0.30	4.0	0.042	0.17	2.2	0.059	0.23	3.1
Commercial	0.081	0.32	4.3	0.057	0.23	3.0	0.070	0.28	3.7
Industrial	0.042	0.17	2.2	0.025	0.099	1.3	0.034	0.13	1.8
Park	0.042	0.17	2.2	-	-	-	-	-	-
Open	0.016	0.063	0.85	0.015	0.059	0.79	0.023[b]	0.091[b]	1.2[b]
Institutional	-	-	-	0.030	0.12	1.60	-	-	-

[a] Average of unpublished data collected by University of Florida, 1975, Guelph, Kingston, Kitchener-Waterloo, Milton, St. Catharines, Sault Ste. Marie, Thunder Bay, West Toronto, Windsor.[23]

[b] Average of open plus park.

$$M = \frac{P_s \cdot C \cdot CR \cdot \rho}{N_D} . \qquad \text{(V-4)}$$

For annual average computations it may be assumed that, on an average basis,

$$P_s = \frac{P}{n} \qquad \text{(V-5)}$$

and

$$N_D = \frac{365}{n} \qquad \text{(V-6)}$$

where P = average annual precipitation, depth/year,

P_s = average precipitation per storm, depth/storm,

N_D = average number of dry days between storms, and

n = average number of storms per year.

Equation V-3 may thus be used to compute average annual values since it results from substitution of equations V-5 and V-6 into equation V-4.

Equation V-3 may be converted to convenient units. For instance,

$$M\left(\frac{lb}{day\text{-}acre}\right) = P\left(\frac{in.}{yr}\right) \cdot C\left(\frac{lb}{10^6\ lb}\right) \cdot CR \cdot 62.4\left(\frac{lb}{ft^3}\right) \cdot \frac{43560}{acre}\ ft^2 \cdot \frac{ft}{12\ in.}$$

$$\frac{yr}{365\ day}$$

or

$$M = 6.21 \times 10^{-4} \cdot P \cdot C \cdot CR \qquad \text{(V-7)}$$

where M = average surface loading, lb/day-acre,

P = annual precipitation, in/yr,

C = pollutant concentration in discharge, mg/l or ppm, and

CR = runoff coefficient, fraction.

Use of equation V-7 suffers from several difficulties. It is inherently an average, and is susceptible to the assumptions of equations V-5 and V-6. It requires the use of a flow weighted average concentration. Unfortunately, such values are seldom reported in the literature, if indeed any specification is made as to the types of "average" concentration presented. Runoff is generated by the simplest of methods, that of a runoff coefficient with all of its well-documented errors.

On the other hand, measured concentrations do in fact represent the real amount of pollutants being discharged, and thus incorporate all of the unknown factors involved in trying to generate surface loads coupled with a wash-off and transport mechanism. These include such factors as dust fall, air pollution and several others not specifically addressed in this study. Furthermore, for purposes of the nationwide assessment performed in this study, very simple methods of runoff and quality generation must be employed. Hence, equation V-7 is consistent with other levels of analysis used in this research.

In the same manner that surface accumulations could be considered functions of population density and land use, so can surface loadings derived from effluent data. In particular, both the concentration and runoff coefficient are clearly such functions; the latter has been discussed in the previous section. In order to ascertain the functional relationship between the surface loadings and population density, available data for the residential areas for which population density is given have been tabulated. Derived surface loadings are given in Table V-5, Surface BOD Loadings for Residential Areas as Derived from Effluent Measurements. The cities included in the table all had data for residential areas for which population density was specified and from which surface loadings could be derived. The list is not meant to be exclusive but represents data that were readily available during the study.

The vast disparity among all the data may be seen in Figure V-4, Residential BOD Loadings vs Developed Population Density. Both separate stormwater and combined sewage loadings vary by over an order of magnitude. Unfortunately, the variation persists if normalized by dividing by annual precipitation (not shown). Three cities -- Atlanta, Bucyrus, and Durham -- produce very high results compared to the bulk of the data. The reason for this is primarily variation from strictly residential land use. In addition, the open channels in Durham had characteristics of open sewers. The values are so high as to be inconsistent with the rest of the data and are omitted from subsequent analysis. The remaining data still show considerable scatter, but will be utilized to derive required relationships.

LOADING PREDICTION FOR NATIONWIDE ASSESSMENT

Form of Equation

Surface pollutant loads generated by the pollutant load estimating equation will be assumed to "wash off" on an annual basis for purposes of the nationwide assessment. Hence, they must be representative of actual measured effluent loads. Moreover, they should be functionally related to causative factors in a reasonable manner. They are expected to be functions of land use and population density. In addition, the extensive presentation of Volume III showed geographical variations in,

Table V-5. SURFACE BOD LOADINGS FOR RESIDENTIAL AREAS AS DERIVED FROM EFFLUENT MEASUREMENTS

Note: Surface loadings are taken directly from the source if computed therein, or derived from mass emission (e.g., lbs/storm) data, if listed. Otherwise equation V-7 is used (for cities for which runoff coefficient and BOD concentration are listed).

City	Site or Station[a]	Sewer System	Catchment Area ac	(ha)	Annual Precip. in.	(cm)	Runoff Coef.	BOD Conc. mg/l	BOD Surface Loading lb/ac-day	(kg/ha - day)	Population Density Persons/ac	(persons/ha)	Reference
Tulsa	3	Separate	550	(223)	48	(122)			0.0381	(0.0428)	7.13	(17.61)	9
	5	"	507	(205)					0.0901	(0.1012)	8.93	(22.06)	
	7	"	197	(80)					0.0617	(0.0692)	11.55	(28.53)	
	8	"	211	(85)					0.0899	(0.1009)	11.37	(28.08)	
	9	"	64	(26)					0.0544	(0.0611)	13.67	(33.76)	
	11	"	815	(330)					0.0963	(0.1081)	9.57	(23.64)	
	13	"	212	(86)					0.0679	(0.0762)	2.36	(5.83)	
	15	"	74	(30)					0.0688	(0.0772)	11.22	(27.71)	
Bucyrus	6	Combined	179	(72)	35	(89)	0.39	120	1.017	(1.142)	11.7	(28.9)	2[c]
	17	"	614	(249)			0.41	107	0.953	(1.070)	9.1	(22.5)	
	23	"	378	(153)			0.35	108	0.821	(0.922)	5.0	(12.4)	
Atlanta	Confed. Ave.	Combined	1129	(457)	48	(122)	0.31	210	1.94	(2.178)	10.9	(26.9)	11
	Blvd.	"	2421	(980)			0.42	84	1.05	(1.179)	16.6	(41.0)	
	McDan St.	"	968	(392)			0.42	386	3.58	(4.019)	13.2	(32.6)	
	Norlan	Separate	954	(386)			0.33	7	0.069	(0.077)	9.7	(24.0)	
	Casplan	"	517	(209)			0.56	20	0.334	(0.375)	7.3	(18.0)	
	Ped. Prin.	"	1498	(606)			0.31	26	0.240	(0.269)	4.8	(11.9)	
Roanoke	Trout Run	Separate	987	(406)	34	(86)			0.0383	(0.0430)	11.0	(27.2)	12[b]
	Murray Run	"	909	(368)					0.0428	(0.0481)	6.6	(16.3)	
	24 St.	"	1034	(419)					0.0233	(0.0262)	9.7	(24.0)	
Milwaukee	Hawley Rd.	Combined	495	(200)	31	(79)	0.46	49	0.377	(0.423)	35.0	(86.5)	13
Wash. D.C.	Good Hope Run	Separate	[illegible]	[illegible]	41	(104)			0.063	(0.071)	37.6	(92.9)	14
	[illegible]	Combined	[illegible]	[illegible]					0.197	(0.221)	[illegible]	[illegible]	
	[illegible]	"	[illegible]	(90)					0.107	(0.120)	[illegible]	[illegible]	
Des Moines	[illegible]	Separate Combined	[illegible]	[illegible]	31	(79)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15
Cincinnati	Mt. Washington	Separate	27	(11)	40	(102)			[illegible]	(0.1011)	[illegible]	[illegible]	16
Durham	[illegible]	Separate	[illegible]	[illegible]	43	(110)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
Seattle	Low Dens.	Separate	c		36	(91)			[illegible]	[illegible]	[illegible]	[illegible]	18
	Med. Dens.	"	c						[illegible]	[illegible]	[illegible]	[illegible]	
	High Dens.	"	c						[illegible]	[illegible]	[illegible]	[illegible]	
Windsor	Lauzon Rd.	Separate	30	(12)	33	(84)			0.059	(0.066)	20.0	(49.4)	19

[a] Site or station as listed in source documentation.

[b] Value computed using imperviousness.

[c] Hypothetical area based on measured data.

[d] Assumed on basis of dwelling units per acre.

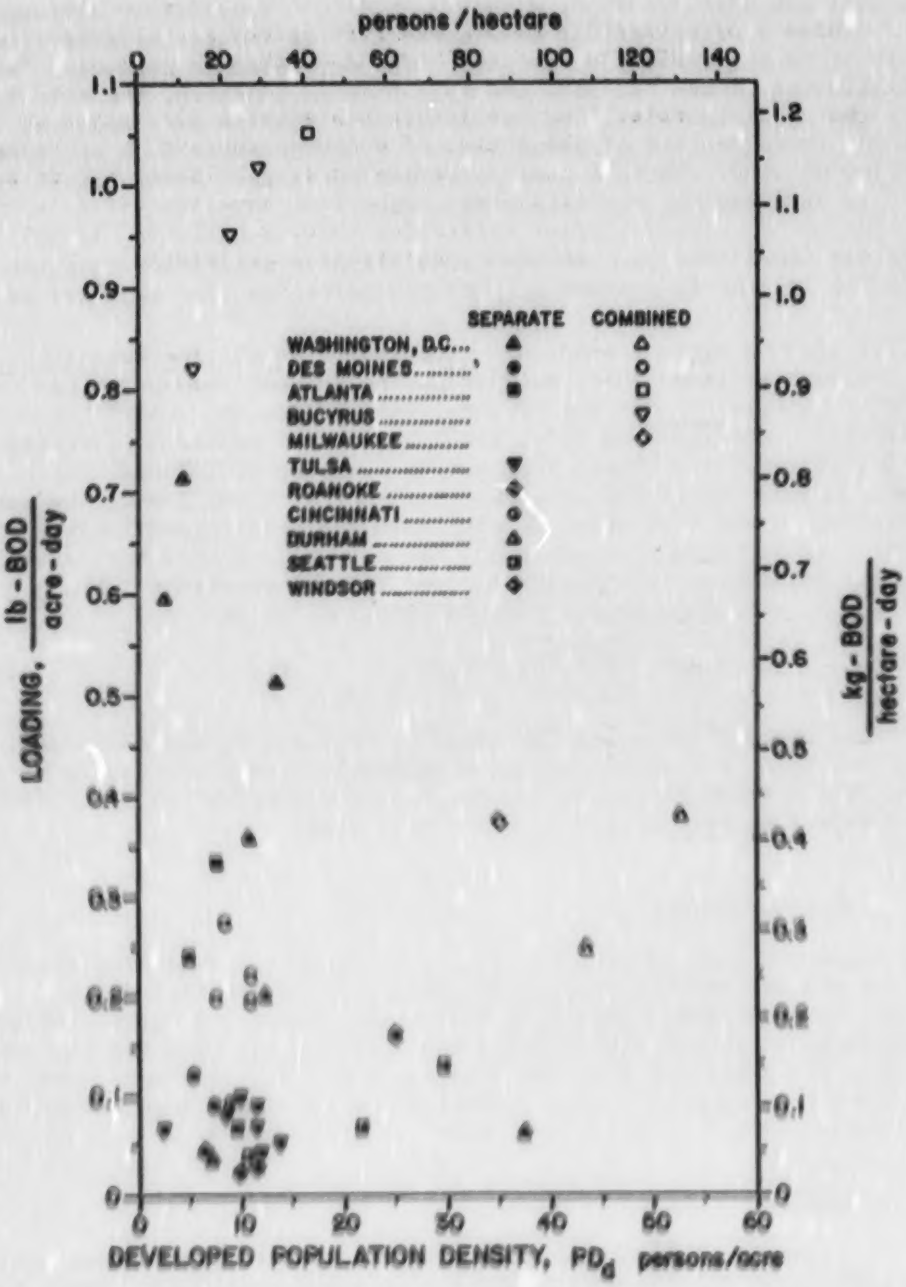

Figure V-4. Residential BOD Loadings vs Developed Population Density

Data are from Table V-5.

say, dust and dirt loadings, although it is not immediately obvious as to how these loadings differ in a commercial or industrial area from one point in the country to another. The key climatic parameter is precipitation, since the more precipitation that occurs, the more likely it is that pollutants will be washed off the surface and appear as effluent loads instead of being removed by other means such as street sweeping or wind. Total annual pollutant loads from storm runoff are lower in arid regions for this very reason.

These considerations led to the selection of a predictive equation in which the loading is proportional to precipitation, for all land uses.

It will also be proportional to a function of population density for residential areas which is intended to account for many other implicit factors such as age of area, imperviousness, runoff coefficient, etc., all of which are functions of population density. Lastly, it is also a function of street sweeping efficiency. This formulation may be easily applied to all parts of the country because precipitation and population density data are readily available. However, these parameters are about the only ones (other than areas) that are available, ruling out more complicated functions. The loading, M, will thus be represented functionally as:

$$M = \alpha \cdot f_1(P) \cdot f_2(PD_d) \cdot f_3(N_s) \qquad \text{(V-8)}$$

where the coefficient α and functions f_1, f_2, and f_3 are to be determined below and N_s is the street sweeping interval. The procedure to be followed will develop appropriate parameters for residential areas first, which will then be extended to other land uses.

Precipitation Function

If average BOD loadings for the cities of Table V-5 (omitting Atlanta, Bucyrus and Durham) are plotted versus annual precipitation (not shown), no clear relationship is indicated. Hence, the data will simply be averaged to obtain the factor α and $f_1(P)$ of equation V-8 for BOD. That is, it is assumed that the loadings are directly proportional to precipitation, such that zero precipitation generates zero stormwater pollution. This is supported by equation V-7. Hence,

$$f_1(P) = P \qquad \text{(V-9)}$$

and the parameter α is obtained as an average of the seven remaining cities of Table V-5 for which separate data are available. Thus, for BOD for residential areas,

$$\alpha = \frac{1}{7} \sum_{i=1}^{7} \frac{\text{loading}_i}{P_i} = \frac{1}{7} \sum_{i=1}^{7} \frac{M_i}{P_i} \tag{V-10}$$

$$= 0.80 \frac{\text{lb-BOD}}{\text{ac-in.}} = 0.35 \frac{\text{kg-BOD}}{\text{ha-cm}}$$

Annual average BOD loadings for residential areas are now predicted by

$$M = 0.80 \cdot P \cdot f_2(PD_d) \cdot f_3(N_s) \tag{V-11}$$

where M = annual average BOD loading for separate sewered, residential areas, lb-BOD/ac-yr,

P = annual precipitation, inches/year,

PD_d = developed population density, persons/acre, and

N_s = street sweeping interval, days.

For combined areas, the equation will be identical, except that a parameter β will be employed instead of α in order to distinguish between combined and separate areas. For BOD for residential areas, the value of β is computed using average values for Des Moines, Milwaukee and Washington, DC from Table V-5

$$\beta = \frac{1}{3} \sum_{i=1}^{3} \frac{\text{loading}_i}{P_i} = \frac{1}{3} \sum_{i=1}^{3} \frac{M_i}{P_i} \tag{V-12}$$

$$= 3.3 \frac{\text{lb-BOD}}{\text{ac-in.}} = 1.5 \frac{\text{kg-BOD}}{\text{ha-cm}}$$

Annual BOD loadings for residential areas served by combined sewers are thus,

$$M = 3.3 \cdot P \cdot f_2(PD_d) \cdot f_3(N_s) \tag{V-13}$$

where parameters are as previously defined.

It may be seen that for the same population density and precipitation, combined BOD loadings are 3.3/0.80 = 4.12 times higher than separate loadings. This agrees with an independent survey of available data by Lager and Smith[20] in which average BOD concentrations in combined sewage of 115 mg/l are 3.83 times greater than the average BOD concentration of 30 mg/l in separate sewers. The difference in loadings is due mainly to residual matter left in conduits between storms since simple mixing of storm water and dry-weather flow, or differences in population density between separate and combined sewer areas will not explain the fourfold variation in concentrations and loadings.

Population Function

The data of Table V-5 and Figure V-4 incorporate all the available information about the relationship of BOD loadings with population density implied by equations V-7 and V-8. In order to extend the data base slightly further, it will be assumed that combined area loadings increase with population density, PD_d, in the same manner as do separate area loadings. The data base can then be extended slightly by normalizing by the average loadings for separate and combined areas. Omitting the data from Atlanta, Bucyrus and Durham, Table V-6, Normalized BOD Loading Data, may be prepared. Finally, the data of Table V-6 may be plotted, as shown in Figure V-5, Normalized BOD Loadings vs Developed Population Density. A point has been added that represents the loading in open space of 0.00982 lb-BOD/ac-day (0.0110 kg-BOD/ha-day) where presumably the population density is zero. (The derivation of this value is shown later.)

Inspection of Figure V-5 shows such scatter that no statistically significant relationship is likely to be derived from the data. Rather, an argument must be made upon the expected form of the functional relationship, and the data used only to obtain a calibration. This relationship is expected to be similar to those developed earlier for imperviousness and curb length, namely increasing rapidly at low population densities and leveling off at high ones.

The concentration of stormwater pollutants is M/AR, or

$$\frac{M}{AR} = \frac{\alpha P[f_2(PD_d)]}{K[0.15 + 0.75\ I]P} \qquad (V\text{-}14)$$

where $$I = 0.096\ PD_d^{(0.573-0.0391\ \log_{10} PD_d)}, \text{ or} \qquad (V\text{-}15a)$$

$$I \approx 0.096\ PD_d^{0.54} \qquad (V\text{-}15b)$$

and K is a conversion factor, for example, the value that appears in equation V-7 in order to achieve units of mg/l. Depression storage is omitted in the approximation of annual runoff. Thus,

$$\frac{M}{AR} = \frac{\alpha[f_2(PD_d)]}{K[0.15 + 0.072\ PD_d^{0.54}]}. \qquad (V\text{-}16)$$

Given that $f_2(PD_d)$ has a minimum where $PD_d = 0$, then a reasonable functional form for $f_2(PD_d)$ is

$$f_2(PD_d) = a + b\ PD_d^{m} \qquad (V\text{-}17)$$

where $a = 0.142$ = value at $PD_d = 0$ (from open space value),

Table V-6. NORMALIZED BOD LOADING DATA

Note: Values obtained from Table V-5, omitting data from Atlanta, Bucyrus and Durham.

	Average Loading lb-BOD/ac-day (kg-BOD/ha-day)	City	Loading/Ave. Loading	Population Density Persons/ac	(Persons/ha)
Separate	0.0693	Tulsa	0.550	7.13	(17.61)
Areas	(0.0778)		1.300	8.93	(22.06)
			0.060	11.55	(28.53)
			1.297	11.37	(28.08)
			0.785	13.67	(33.76)
			1.390	9.57	(23.64)
			0.980	2.36	(5.83)
			0.993	11.22	(27.71)
		Roanoke	0.524	11.0	(27.2)
			0.617	6.6	(16.3)
			0.336	9.7	(24.0)
		Wash. D.C.	0.909	37.6	(92.9)
		Des Moines	1.342	7.4	(18.3)
			1.746	5.3	(13.1)
		Cincinnati	1.305	9.0	(22.2)
		Seattle	0.577	11.0	(27.2)
			1.010	22.0	(54.3)
			1.876	30.0	(74.1)
		Windsor	0.851	20.0	(61.8)
Combined	0.271	Wash. D.C.	0.911	43.6	(107.7)
Areas			1.405	52.6	(129.9)
	(0.304)	Milwaukee	1.391	35.0	(86.5)
		Des Moines	0.734	7.5	(18.5)
			1.014	8.3	(20.5)
			0.727	10.9	(26.9)
			0.819	10.9	(26.9)

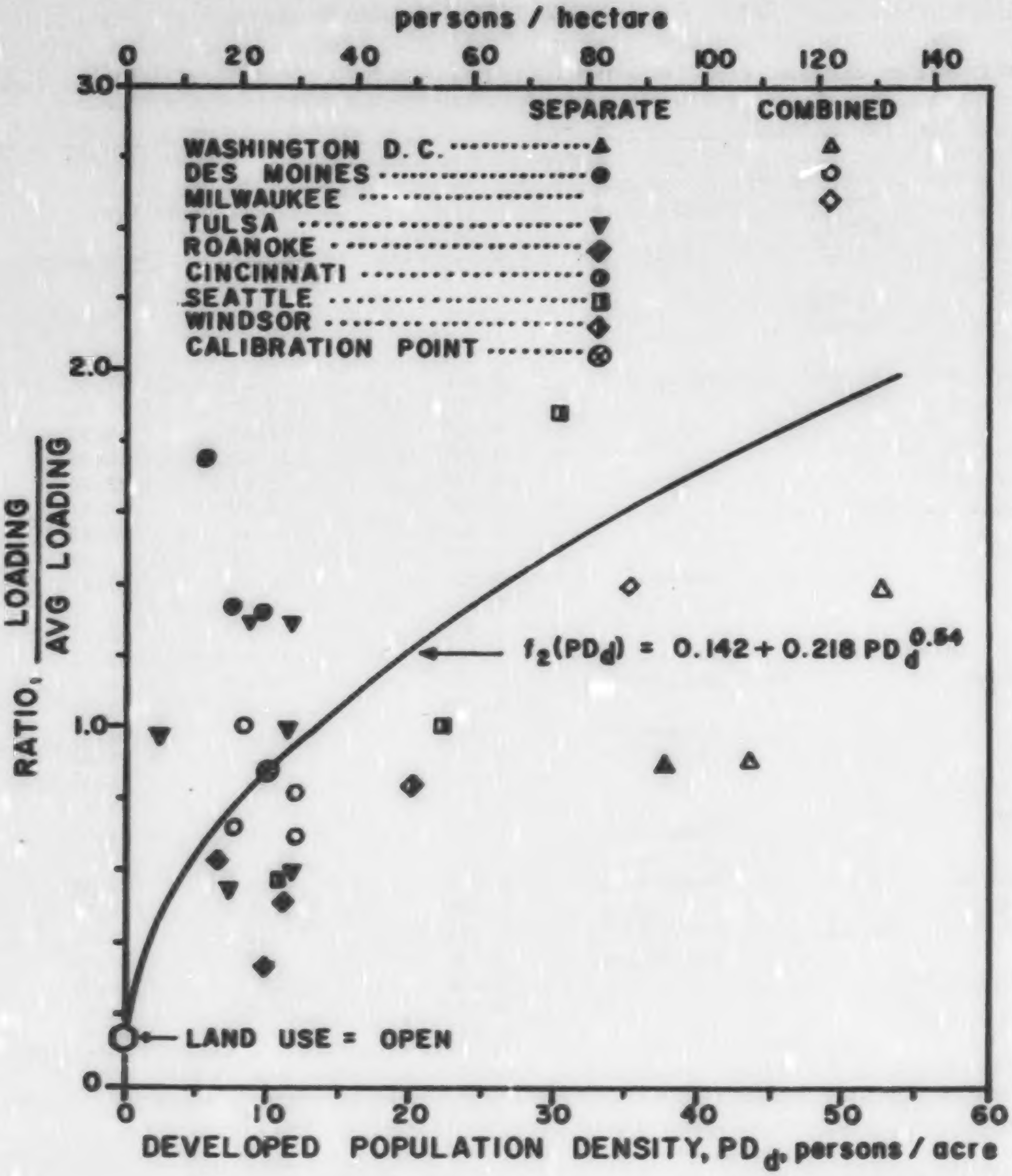

Figure V-5. Normalized BOD Loadings vs Developed Population Density. Data from Table V-6.

and developed population density will be used for consistency. Note that, depending on the assumed value of m, the concentration of storm water pollution will vary accordingly. Since no firm arguments can be made on the nature of the concentration function, it will be assumed that m is equal to the approximate exponent in the runoff equations or $m = 0.54$. Thus, $f_2(PD_d) = 0.142 + b\ PD_d^{0.54}$. Lastly, all data points with a PD_d ranging from 5 to 15 persons per acre (12 to 37 persons/ha) are averaged to obtain a calibrated value of $f_2(PD_d) = 0.895$ at 10 persons per acre (25 persons/ha). This range is chosen because data from most cities fall within it. Thus, the final equation is

$$f_2(PD_d) = 0.142 + 0.218\ PD_d^{0.54} \qquad \text{(V-18)}$$

where PD_d = developed population density, persons per acre.

The reasonableness of equation V-18 can be checked by estimating the variation in concentration as a function of population density. From equations V-11 and V-18, the annual BOD loading is

$$M = 0.80 \cdot P \cdot (0.142 + 0.218\ PD_d^{0.54}) \qquad \text{(V-19)}$$

and annual runoff, AR, using the approximate New Jersey[21] equation (equation V-15b) for imperviousness is:

$$AR = [0.15 + 0.75(0.096)PD_d^{0.54}] \cdot P \qquad \text{(V-20)}$$

Thus,

$$\frac{M}{AR} = \frac{0.113 + 0.174\ PD_d^{0.54}}{K[0.15 + 0.072\ PD_d^{0.54}]} \qquad \text{(V-21)}$$

Using K = 0.227 to convert to mg/l from the ratio of lbs/ac-yr per in./yr this ratio, which is plotted in Figure V-6, BOD Concentration Variation Using Estimating Equation, shows concentration increasing with population density which does seem reasonable. The range of average annual concentrations is lower than values shown in Table V-5 since it represents the average over the total residential area of a city. Unquestionably, the data base for estimating pollutant loads is very weak, and the resulting estimating equation, supported by such a weak foundation should be used with extreme caution.

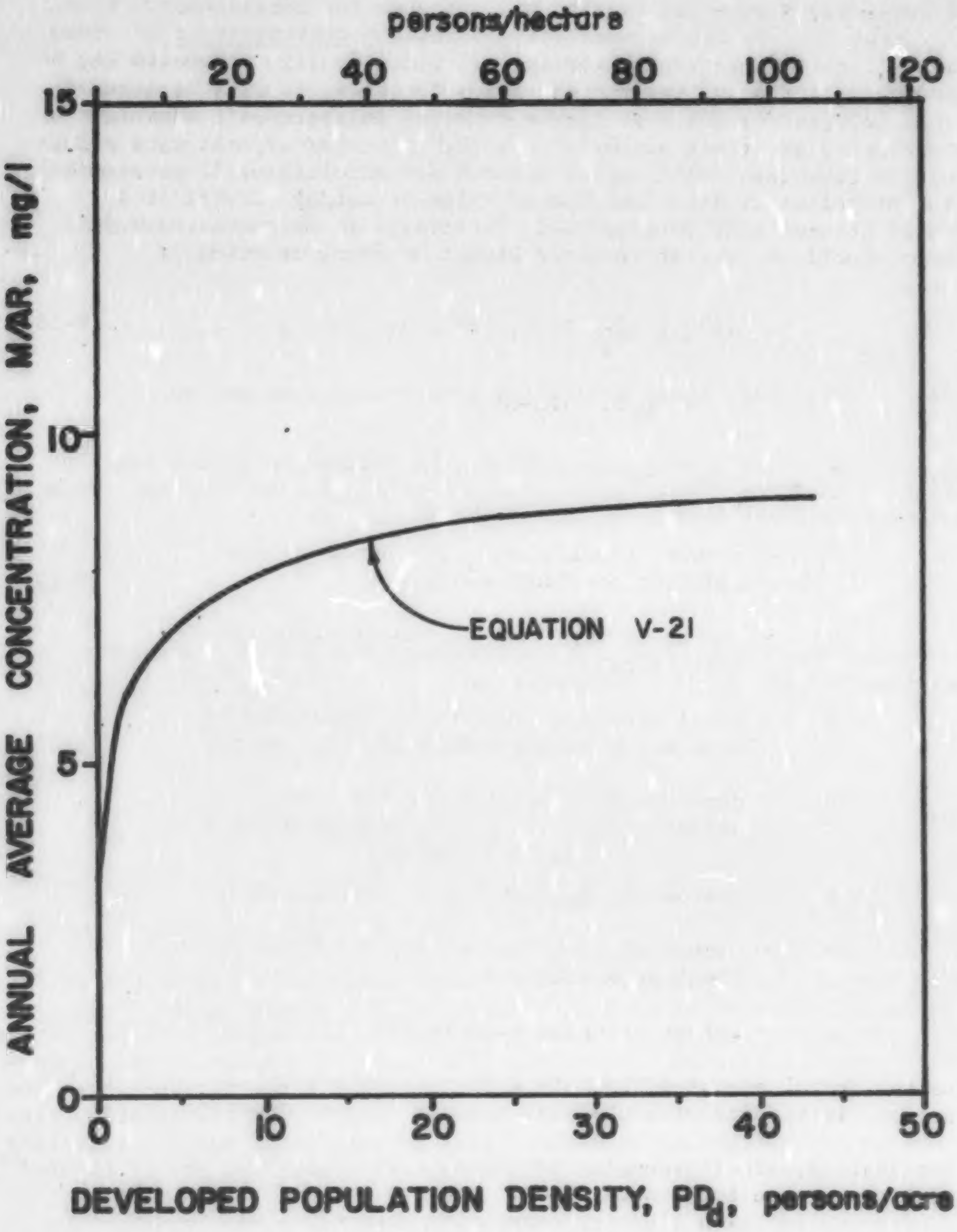

Figure V-6. BOD Concentration Variation Using Estimating Equation

Adjustment for Street Sweeping

In STORM, the computation of stormwater runoff quality parameters is dependent upon the analysis of the accumulation and washoff rate of the various pollutant loads. Related to the accumulation of pollutants is the frequency of street sweeping. If the number of days since the last runoff is less than the interval between street sweepings, the accumulation of pollutant j on land use i at the beginning of a storm is computed according to equation V-1. However, if the number of days without runoff is greater than the street sweeping interval, $P_{i,j}$ is computed as

$$P_{i,j} = P_o(1-\varepsilon)^n + N_s DD_i F_{i,j}[(1-\varepsilon)^n + (1-\varepsilon)^{n-1} + \ldots + (1-\varepsilon)] + DD_i F_{i,j}(N_D - nN_s) \qquad \text{(V-22)}$$

where $P_{i,j}$ = total pounds of pollutant j on land use i at the beginning of the storm,

$F_{i,j}$ = pounds of pollutant j per pound of dust and dirt for land use i,

N_D = number of days without runoff since the last storm,

P_o = total pounds of pollutant j remaining on land use i at the end of the last storm,

DD_i = dust and dirt loading for land use i, lb/day = $dd_i \cdot G_{L,i} \cdot A_i$ from equation V-1,

N_s = number of days between street sweeping,

n = number of times the street was swept since the last storm, and

ε = street sweeping efficiency.

Note that total pounds of pollutant (not soluble only) are used in the equation, in keeping with the discussion following equation V-1.

Unfortunately, street sweeping frequencies and efficiencies are often not readily available for a study area. One can see that this is not a parameter to be taken lightly, especially when equation V-22 is used to compute pollutant accumulations. Nevertheless, it can be shown that, if the street sweeping interval is sufficiently large, it has no significant effect on pollutant accumulation and runoff quality. This is due to the fact that storms that occur within this interval will wash off the pollutants before they can build up and be removed by a sweeper.

The City of Des Moines, Iowa was chosen to demonstrate this contention. Des Moines is a moderately sized city with approximately 255,000 people and an annual average precipitation comparable to the national average. STORM was run using the precipitation record for the year 1968. Previously calibrated loading factors were also used. The street sweeping frequency was varied and the effect on the computation of annual average BOD and suspended solids concentration noted. The results are shown in Figure V-7, Effect of Street Sweeping Frequency on Annual BOD Concentration in Urban Stormwater Runoff - Des Moines, Iowa.

The results show that there is a point after which the magnitude of the street sweeping frequency has no effect on the computed values of average annual BOD and suspended solids concentrations. In this case, after approximately 20 days, STORM was insensitive to changes of the street sweeping interval. Thus,

$$f_3(N_s) = \gamma = \begin{cases} N_s/20 \text{ if } 0 \leq N_s \leq 20 \text{ days} \\ 1 \text{ otherwise} \end{cases} \qquad \text{(V-23)}$$

where γ = proportion of pollutant load remaining after street sweeping, and

N_s = street sweeping interval, days.

Due to insufficient data on street sweeping frequencies and associated control costs in the 248 urbanized areas, no adjustment was made in the calculated loadings to account for removal due to sweeping. Alternatively, γ was set equal to 1 for all cities.

Conversion for Alternate Land Uses and Pollutants

Different pollutants and land uses will generate different loadings for at least three reasons. First the dust and dirt loadings for different land uses differ. Second, the conversion factor of curb length per area is different for different land uses. Third, the pollutant fractions (as a fraction of dust and dirt) are different for different land uses. These factors are used to extend the equations developed for BOD for residential areas to similar equations for commercial, industrial and open land uses and for suspended solids, volatile solids, total PO_4 and total N.

It is assumed that fractions and ratios of pollutants as they appear in effluents will be the same as those determined from analysis of surface accumulation data. The parameters shown in Table V-7, Surface Loading and Pollutant Fraction Data, are used for conversion purposes. They are selected from the extensive survey material presented in Volume III. Where no data are available for pollutants as a fraction of surface dust and dirt, use is made (as a second choice) of similar

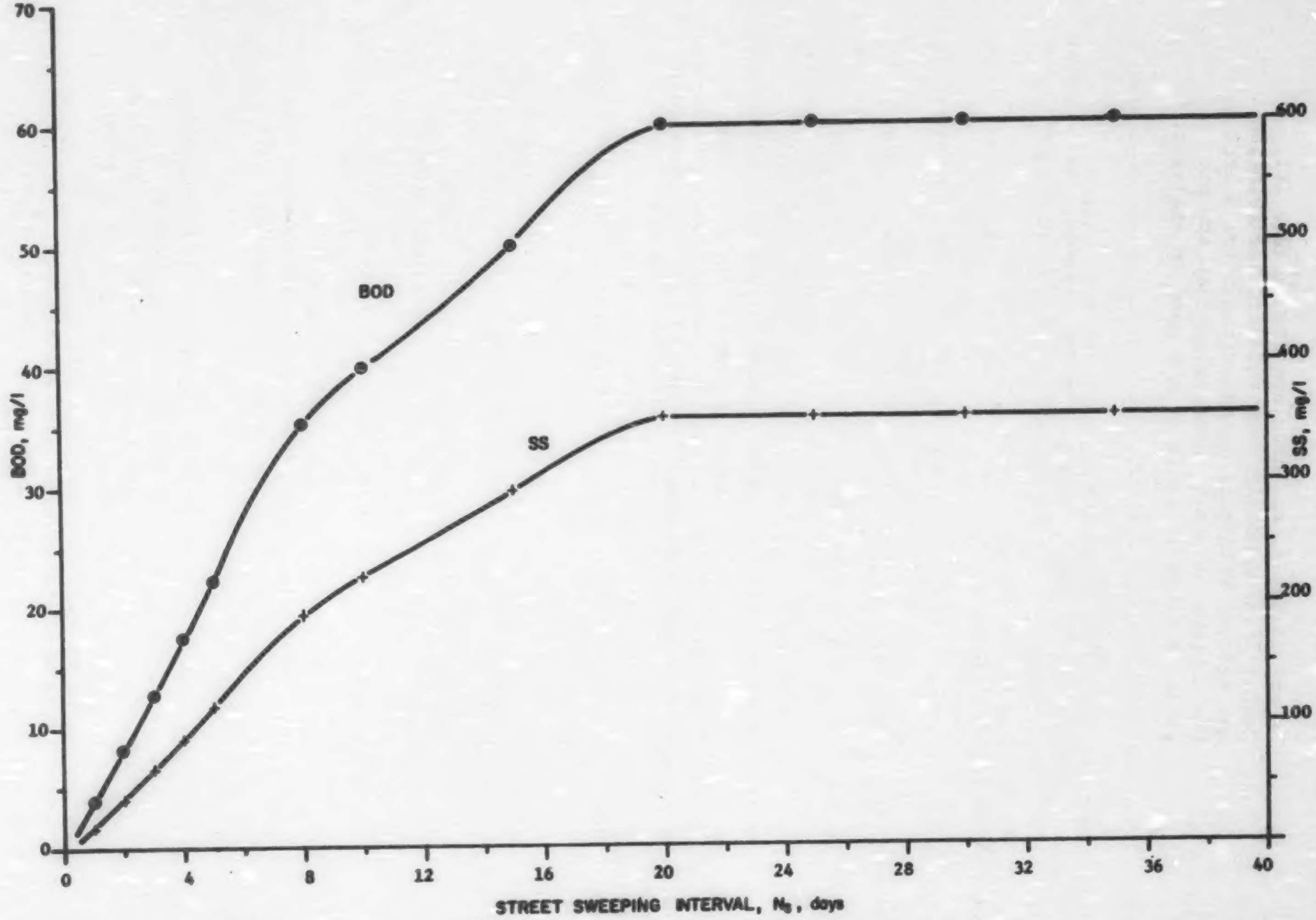

Figure V-7. Effect of Street Sweeping Frequency on Annual BOD Concentration in Urban Stormwater Runoff - Des Moines, Iowa. The variation of SS concentration is also shown.

Table V-7. SURFACE LOADING AND POLLUTANT FRACTION DATA

Except as noted, all data are from Volume III, Table: "Average Daily Dust and Dirt Accumulation and Related Pollutant Concentrations for Select Field Observations." Missing entries are not given in original table or not used in analysis.

	Residential						
	Single Family	Mult Family	Average	Commercial	Industrial	Open[a]	All Data
Dust and Dirt							
Accumulation dd_i $\frac{lb}{day\text{-}curb\ mile}$	62	113	87.5	166	319	50	159
$\frac{g}{day\text{-}curb\ mile}$	17	32	24.8	47	90	14.2	45
BOD - ppm of dd_1	5260	3370		7190	2920		
ppm of total solids (TS)[a]			29840	83800	25850	18990	
Total PO_4 - ppm of dd_1							170
ppm of TS[a]						1670	
Total N - ppm of dd_1							664[b]
ppm of TS[a]						10170[c]	
Suspended Solids-ppm of TS[a]			609200	582300	619500	453200	
Volatile Solids-ppm of TS[a]			353000	367700	306100	437500	

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[a] Values taken from Volume III, Table: "Mean Pollutant Concentrations for Total Solids and Street Solids Accumulations."

[b] Sum of K-N plus NO_3-N.

[c] Value of organic - N only.

data developed for pollutants as a fraction of total solids (TS).

The BOD data are first converted to other land uses using equation V-1 as indicated below, and using i = residential (res) land use as the reference:

$$\alpha(i,\mathrm{BOD}) = \alpha(\mathrm{res},\mathrm{BOD}) \cdot \frac{dd_i}{dd_{\mathrm{res}}} \cdot \frac{G_{L,i}}{G_{L,\mathrm{res}}} \cdot \frac{F_{i,\mathrm{BOD}}}{F_{\mathrm{res},\mathrm{BOD}}} \qquad (V\text{-}24)$$

where dd_i = dust and dirt accumulation on land use i, lb/day-curb mile,

$G_{L,i}$ = curb miles per acre for land use i from Table V-4, and

$F_{i,\mathrm{BOD}}$ = fraction of dust and dirt that is BOD on land use i.

For example, the parameter α for BOD for commercial land use for separate areas is

$$\alpha(\mathrm{com},\mathrm{BOD}) = 0.80 \cdot \frac{166 \times 7190}{353465} \cdot \frac{0.070}{0.059} = 3.2 \ \frac{\text{lb-BOD}}{\text{ac-in.}} = 1.4 \ \frac{\text{kg-BOD}}{\text{ha-cm}} \qquad (V\text{-}25)$$

where the number 353,465 is the average product of $dd_i \cdot F_{i,j}$ for j = BOD and i = single and multi-family residential and is equal to

$$\frac{62 \times 5260 + 113 \times 3370}{2} \, .$$

After determination of BOD for each land use, i, other quality parameters, j, are computed on the basis of relative values of the fractions, $F_{i,j}$. Thus,

$$\alpha(i,j) = \alpha(i,\mathrm{BOD}) \ \frac{F_{i,j}}{F_{i,\mathrm{BOD}}} \, . \qquad (V\text{-}26)$$

For example, the parameter α for total PO_4 in commercial areas is

$$\alpha(\mathrm{com},PO_4) = 3.2 \times \frac{170}{7190} = 0.076 \ \frac{\text{lb-}PO_4}{\text{ac-in.}} = 0.034 \ \frac{\text{kg-}PO_4}{\text{ha-cm}} \, . \qquad (V\text{-}27)$$

For total nitrogen, N, in residential areas the calculation is similar but includes the average product of $dd_i \cdot F_{i,j}$,

$$\alpha(\text{res,N}) = \frac{0.80 \cdot 664 \cdot (62 + 113)/2}{353{,}465} = 0.13 \ \frac{\text{lb-N}}{\text{ac-in.}} \qquad \text{(V-28)}$$

$$= 0.058 \ \frac{\text{kg-N}}{\text{ha-cm}}$$

For open land use and for suspended solids and volatile solids no data are available for fractions of dust and dirt, so fractions of total solids are used for values of F in the ratios. For example, for suspended solids in commercial areas,

$$\alpha(\text{com,SS}) = 3.2 \times \frac{582{,}300}{83{,}800} = 22 \ \frac{\text{lb-SS}}{\text{ac-in.}} \qquad \text{(V-29)}$$

$$= 9.8 \ \frac{\text{kg-SS}}{\text{ha-cm}} \ .$$

Computations for combined areas are carried out in the same manner to calculate the β parameters. The final result is shown in Table V-8, Pollutant Loading Factors for Nationwide Assessment. Use of the same adjustment factors for combined and separate areas leads to the same ratio $\beta/\alpha = 4.12$ for all entries in the table. The assumption is probably not too bad, although some studies have shown higher ratios of volatile solids to suspended solids, for example, in combined sewage than in storm runoff alone.[22]

The BOD loadings are compared to dry-weather flow loadings in Table V-9, Comparison of BOD Loadings, for residential land use. Storm and combined runoff can be seen to be comparable to treatment plant effluent, although on a city-wide basis they would be greater because of higher loadings for commercial and industrial areas. Of course, BOD loads in both storm and combined sewage are in addition to the dry-weather flow loads since the usual BOD load for the latter of 0.17 lb/person-day (0.08 kg/person-day) is based upon measurements of flows actually received at treatment plants. The data from which the loadings shown in Table V-8 were derived reflect discharges over and above those received by the plants.

TABULATION OF NATIONWIDE BOD LOADS

In order to minimize the volume of material presented for each city in the assessment, only BOD loadings were tabulated. The equations indicated in Table V-8 may easily be used to calculate loadings of any of the desired parameters, given the precipitation and population density of the area of interest. As described in Section III, land use variations are determined by first computing the fraction of undeveloped land in the urbanized area. The remaining land has a constant distribution

Table V-8. POLLUTANT LOADING FACTORS FOR NATIONWIDE ASSESSMENT

The following equations may be used to predict annual average loading rates as a function of land use, precipitation and population density.

Separate Areas: $M_s = \alpha(i,j) \cdot P \cdot f_2(PD_d) \cdot \gamma \ \frac{\text{lb}}{\text{acre-yr}}$

Combined Areas: $M_c = \beta(i,j) \cdot P \cdot f_2(PD_d) \cdot \gamma \ \frac{\text{lb}}{\text{acre-yr}}$

where M = pounds of pollutant j generated per acre of land use i per year,
P = annual precipitation, inches per year,
PD_d = developed population density, persons per acre,
α, β = factors given in table below,
γ = street sweeping effectiveness factor, and
$f_2(PD_d)$ = population density function.

Land Uses: i = 1 Residential
i = 2 Commercial
i = 3 Industrial
i = 4 Other Developed, e.g., parks, cemeteries, schools (assume $PD_d = 0$)

Pollutants: j = 1 BOD_5, Total
j = 2 Suspended Solids (SS)
j = 3 Volatile Solids, Total (VS)
j = 4 Total PO_4 (as PO_4)
j = 5 Total N

Population Function: i = 1 $f_2(PD_d) = 0.142 + 0.218 \cdot PD_d^{0.54}$
i = 2,3 $f_2(PD_d) = 1.0$
i = 4 $f_2(PD_d) = 0.142$

Factors α and β for Equations: Separate factors, α, and combined factors, β, have units lb/acre-in. To convert to kg/ha-cm, multiply by 0.442.

		Pollutant, j				
	Land Use, i	1. BOD_5	2. SS	3. VS	4. PO_4	5. N
Separate Areas, α	1. Residential	0.799	16.3	9.45	0.0336	0.131
	2. Commercial	3.20	22.2	14.0	0.0757	0.296
	3. Industrial	1.21	29.1	14.3	0.0705	0.277
	4. Other	0.113	2.70	2.6	0.00994	0.0605
Combined Areas, β	1. Residential	3.29	67.2	38.9	0.139	0.540
	2. Commercial	13.2	91.8	57.9	0.312	1.22
	3. Industrial	5.00	120.0	59.2	0.291	1.14
	4. Other	0.467	11.1	10.8	0.0411	0.250

Street Sweeping: Factor γ is a function of street sweeping interval, N_s, (days):

$$\gamma = \begin{cases} N_s/20 & \text{if } 0 \leq N_s \leq 20 \text{ days} \\ 1.0 & \text{if } N_s > 20 \text{ days} \end{cases}$$

Table V-9. COMPARISON OF BOD LOADINGS

Assume residential land use; $PD_d = 10$ persons/acre (24.7 persons/ha), $P = 30$ in./yr (76 cm/yr), and $\gamma = 1$.

	lb/ac-yr	kg/ha-yr
Separate Areas	21	24
Combined Areas	88	99
Dry Weather	621	697
DWF at 85% Treatment[a]	93	105

[a] Assuming 0.17 lb-BOD/persons-day (0.08 kg-BOD/person-day).

of land uses, and can be used to weight the pollutant loading factors to give an average over all land uses as follows:

$$\overline{M} = P \sum_{i=1}^{4} w_i \cdot \alpha(i,j) \cdot f_{2_i}(PD_d) \cdot \gamma. \qquad \text{(V-30)}$$

The land use distribution fractions, w_i, are given below from Table III-3:

i	Land Use	Fraction, w_i
1	Residential	0.584
2	Commercial	0.086
3	Industrial	0.148
4	Open	0.182
		1.000

When equation V-30 is applied to BOD loadings for separate areas, the result is

$$\overline{M} = 0.42 \cdot P \cdot (0.142 + 0.218\ PD_d^{0.54}) + 0.46P \qquad \text{(V-31)}$$

where $\overline{M}$ = average annual BOD loadings over four land uses, lb-BOD/ac-yr,

P = annual precipitation, in./yr, and

PD_d = developed population density, persons/acre.

For application to combined areas, the result is

$$\overline{M} = 1.73 \cdot P \cdot (0.142 + 0.218\ PD_d^{0.54}) + 1.9P. \qquad \text{(V-32)}$$

These composite equations may easily be applied over the selected areas. The results are shown for combined, storm (separate), unsewered (using loadings for separate areas) and total land areas in Table V-10, Wet-Weather BOD Loadings. BOD loadings are the only ones computed for the sake of brevity. Values for other pollutants may be easily calculated using Table V-8 and equation V-30.

Dry-weather flow loadings are computed simply on the basis of population density assuming average annual BOD generation of 0.17 lb/person-day (0.08 kg/person-day). Thus, BOD loadings are

$$M_{Dw} = 62.1\ PD_d \qquad \text{(V-33)}$$

where M_{Dw} = average annual dry-weather flow BOD loading, lb-BOD/ac-yr.

In combined sewers, deposition during dry-weather flow can amount to as much as ten percent of the value of equation V-33, on an annual basis.[24] This could properly be subtracted from equation V-33 when used in combined sewered areas since equation V-32 implicitly includes this deposition. However, this refinement was not included in the assessment.

Values calculated using equation V-33 are presented in Table V-11, Dry-Weather BOD Loadings. As would be expected, the most heavily urbanized areas, USEPA regions 2 and 3, have the highest wet-and dry-weather BOD loadings. It may be also noted that for the same population density, areas with a large component of combined sewers produce higher loads.

TABLE V-10 WET-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	TN/YR ANNL. PRECP	WET-WEATHER BOD (LBS/ACRE-YEAR)			
				COMB	STORM	UNSEW	AVER
1	CT	BRIDGEPORT	42.0	151.7	36.9	30.8	47.1
1	CT	BRISTOL	43.0	0.0	38.7	30.4	33.5
1	CT	DANBURY	42.0	0.0	36.7	30.0	32.8
1	CT	HARTFORD	42.0	154.1	37.4	30.5	61.5
1	CT	MERIDEN	43.0	0.0	39.6	32.0	34.8
1	CT	NEW BRITAIN	43.0	0.0	37.0	32.3	33.1
1	CT	NEW HAVEN	45.0	161.8	39.2	33.4	62.5
1	CT	NORWALK	44.0	210.5	32.0	32.0	52.2
1	CT	STAMFORD	45.0	0.0	36.2	33.3	36.0
1	CT	WATERBURY	46.0	166.8	40.8	33.7	48.3
1	CT	OTHER URBAN AREAS	43.7	158.6	37.8	31.8	56.9
1	CT	AVE. FOR STATE	43.7	158.6	37.8	31.8	56.9
1	ME	LEWISTON	44.0	152.8	0.0	30.6	89.5
1	ME	PORTLAND	43.0	140.3	0.0	34.1	111.3
1	ME	OTHER URBAN AREAS	43.5	144.3	0.0	32.1	102.4
1	ME	AVE. FOR STATE	43.5	144.3	0.0	32.1	102.4
1	MA	BOSTON	43.0	164.3	39.9	30.3	44.5
1	MA	BROCKTON	45.0	0.0	39.5	33.1	36.1
1	MA	FALL RIVER	45.0	163.8	39.7	33.0	82.6
1	MA	FITCHBURG	46.0	165.9	40.3	32.8	54.4
1	MA	LAWRENCE	41.0	142.3	0.0	31.1	84.1
1	MA	LOWELL	40.0	148.6	36.0	28.7	64.3
1	MA	NEW BEDFORD	41.0	145.1	35.3	30.8	103.4
1	MA	PITTSFIELD	44.0	0.0	38.8	31.3	34.0
1	MA	SPRINGFIELD	45.0	147.8	0.0	35.9	91.2
1	MA	WORCESTER	46.0	177.0	39.4	34.2	46.7
1	MA	OTHER URBAN AREAS	43.6	152.9	39.7	31.6	56.9
1	MA	AVE. FOR STATE	43.6	152.9	39.7	31.6	56.9
1	NH	MANCHESTER	40.0	138.5	0.0	29.5	93.7
1	NH	NASHUA	42.0	136.8	0.0	33.2	94.3
1	NH	OTHER URBAN AREAS	41.0	137.8	0.0	31.0	94.0
1	NH	AVE. FOR STATE	41.0	137.8	0.0	31.0	94.0
1	RI	PROVIDENCE	40.0	152.9	34.6	28.8	59.1
1	RI	OTHER URBAN AREAS	40.0	152.9	34.6	28.8	59.1
1	RI	AVE. FOR STATE	40.0	152.9	34.6	28.8	59.1
1	VT	URBAN AREAS	35.0	117.7	0.0	27.9	68.5
1	VT	AVE. FOR STATE	35.0	117.7	0.0	27.9	68.5
1		AVE. FOR REGION 1	41.1	149.6	38.7	31.3	62.2
2	NJ	ATLANTIC CITY	42.0	0.0	37.8	29.6	32.8
2	NJ	NEW YORK CITY METRO	43.0	199.1	39.5	30.0	35.3
2	NJ	PHILADELPHIA METRO	43.0	148.2	0.0	27.8	144.9
2	NJ	TRENTON	42.0	0.0	36.1	31.6	35.0
2	NJ	VINELAND	44.0	0.0	37.4	31.9	33.8
2	NJ	AVE. FOR STATE	42.8	160.1	39.2	30.1	38.2
2	NY	ALBANY	38.0	141.3	34.3	27.2	67.7
2	NY	BINGHAMPTON	36.0	123.2	0.0	27.1	103.6
2	NY	BUFFALO	36.0	139.5	29.7	26.5	70.2
2	NY	NEW YORK CITY	43.0	243.5	46.2	0.0	134.1
2	NY	ROCHESTER	32.0	124.1	30.1	22.5	47.6
2	NY	SYRACUSE	38.0	139.6	33.2	28.2	65.7
2	NY	UTICA	44.0	157.6	38.5	32.6	88.1
2	NY	OTHER URBAN AREAS	38.1	190.8	41.1	26.5	95.9
2	NY	AVE. FOR STATE	38.1	190.8	41.1	26.5	95.9
2		AVE. FOR REGION 2	40.5	187.8	40.1	29.2	64.4

TABLE V-10 WET-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL PRECP	WET-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
3	DE	WILMINGTON	45.0	162.2	39.4	33.3	55.5
3	DE	OTHER URBAN AREAS	45.0	162.2	39.4	33.3	55.5
3	DE	AVE. FOR STATE	45.0	162.2	39.4	33.3	55.5
3	DC	WASHINGTON,D.C.	41.0	187.4	37.1	0.0	87.8
3	DC	AVE. FOR STATE	41.0	187.4	37.1	0.0	87.8
3	MD	BALTIMORE	43.0	0.0	38.3	31.7	36.3
3	MD	WASHINGTON DC METRO	41.0	0.0	36.5	24.8	33.6
3	MD	OTHER URBAN AREAS	42.0	0.0	38.0	31.0	35.6
3	MD	AVE. FOR STATE	42.0	0.0	38.0	31.0	35.6
3	PA	ALLENTOWN	44.0	162.0	39.4	32.0	37.0
3	PA	ALTOONA	44.0	155.8	37.9	33.1	57.4
3	PA	ERIE	38.0	135.5	32.6	28.6	50.0
3	PA	HARRISBURG	38.0	141.2	35.3	27.8	38.1
3	PA	JOHNSTOWN	45.0	155.3	37.7	34.8	38.6
3	PA	LANCASTER	43.0	151.8	36.9	32.5	75.1
3	PA	PHILADELPHIA	43.0	161.2	37.9	31.9	40.6
3	PA	PITTSBURGH	37.0	151.9	36.9	24.6	45.7
3	PA	READING	42.0	0.0	36.1	31.6	34.9
3	PA	SCRANTON	39.0	130.9	0.0	29.6	44.6
3	PA	WILKES-BARRE	39.0	140.0	38.0	28.8	54.2
3	PA	YORK	40.0	0.0	34.0	30.5	32.7
3	PA	OTHER URBAN AREAS	41.0	147.0	37.4	28.0	45.1
3	PA	AVE. FOR STATE	41.0	147.0	37.4	28.0	45.1
3	VA	LYNCHBERG	40.0	128.4	0.0	0.0	128.4
3	VA	NEWPORT NEWS	45.0	0.0	39.8	32.4	35.2
3	VA	NORFOLK	45.0	0.0	41.0	31.6	35.2
3	VA	PETERSBURG	43.0	0.0	38.3	30.2	33.0
3	VA	RICHMOND	44.0	159.6	38.8	32.3	74.0
3	VA	ROANOKE	42.0	148.6	36.1	31.6	35.0
3	VA	WASHINGTON DC METRO	41.0	157.1	37.1	0.0	39.1
3	VA	OTHER URBAN AREAS	42.9	147.8	38.3	31.8	45.8
3	VA	AVE. FOR STATE	42.9	147.8	38.3	31.8	45.8
3	WV	CHARLESTON	45.0	162.5	39.5	33.0	78.8
3	WV	HUNTINGTON	40.0	135.7	0.0	0.0	135.7
3	WV	STEUBENVILLE METRO	40.0	125.7	0.0	0.0	125.7
3	WV	WHEELING	39.0	134.7	32.7	30.2	97.1
3	WV	OTHER URBAN AREAS	41.0	137.6	38.6	32.3	104.1
3	WV	AVE. FOR STATE	41.0	137.6	38.6	32.3	104.1
3		AVE. FOR REGION 3	42.1	147.5	37.8	29.6	47.9

TABLE V-10 WET-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	WET-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER.
4	AL	BIRMINGHAM	53.0	0.0	45.8	39.6	42.3
4	AL	GADSDEN	55.0	0.0	48.1	39.3	42.4
4	AL	HUNTSVILLE	52.0	0.0	45.6	36.8	40.0
4	AL	MOBILE	68.0	0.0	59.5	49.2	52.9
4	AL	MONTGOMERY	54.0	0.0	47.2	39.9	43.1
4	AL	TUSCALOOSA	51.0	0.0	44.3	41.2	42.0
4	AL	OTHER URBAN AREAS	55.0	0.0	48.7	41.6	44.4
4	AL	AVE. FOR STATE	55.0	0.0	48.7	41.6	44.4
4	FL	FT.LAUDERDALE	60.0	0.0	53.3	43.6	48.1
4	FL	GAINESVILLE	52.0	0.0	46.6	39.3	41.5
4	FL	JACKSONVILLE	53.0	0.0	46.8	37.7	41.1
4	FL	MIAMI	60.0	0.0	53.0	44.3	50.3
4	FL	ORLANDO	51.0	190.0	46.2	36.0	41.2
4	FL	PENSACOLA	63.0	0.0	55.5	46.0	50.2
4	FL	ST.PETERSBURG	55.0	0.0	49.7	39.4	44.1
4	FL	TALLAHASSEE	57.0	0.0	50.5	41.4	45.4
4	FL	TAMPA	52.0	0.0	47.6	36.7	41.3
4	FL	WEST PALM BEACH	62.0	0.0	54.2	45.5	49.0
4	FL	OTHER URBAN AREAS	56.5	190.0	51.0	40.8	45.9
4	FL	AVE. FOR STATE	56.5	190.0	51.0	40.8	45.9
4	GA	ALBANY	48.0	152.0	0.0	0.0	152.0
4	GA	ATLANTA	47.0	166.9	40.6	35.4	46.2
4	GA	AUGUSTA	39.0	129.2	0.0	31.8	79.6
4	GA	COLUMBUS	49.0	172.8	42.0	37.0	58.9
4	GA	MACON	44.0	0.0	38.4	32.5	35.1
4	GA	SAVANNAH	52.0	197.4	38.5	38.0	84.3
4	GA	OTHER URBAN AREAS	46.5	159.7	40.4	35.3	58.6
4	GA	AVE. FOR STATE	46.5	159.7	40.4	35.3	58.6
4	KY	HUNTINGTON METRO	40.0	141.0	34.3	30.7	43.4
4	KY	LEXINGTON	44.0	0.0	38.0	33.0	36.4
4	KY	LOUISVILLE	41.0	152.8	37.1	29.4	35.4
4	KY	OWENSBORO	44.0	155.7	37.8	33.1	114.4
4	KY	OTHER URBAN AREAS	42.3	153.2	37.2	30.0	39.9
4	KY	AVE. FOR STATE	42.3	153.2	37.2	30.0	39.8
4	MS	BILOXI	58.0	0.0	49.6	43.8	45.8
4	MS	JACKSON	51.0	0.0	44.4	37.8	40.8
4	MS	OTHER URBAN AREAS	54.5	0.0	46.2	40.5	42.9
4	MS	AVE. FOR STATE	54.5	0.0	46.2	40.5	42.9
4	NC	ASHEVILLE	48.0	0.0	43.1	33.9	37.4
4	NC	CHARLOTTE	43.0	0.0	36.8	32.5	34.5
4	NC	DURHAM	43.0	0.0	36.2	33.4	34.6
4	NC	FAYETTEVILLE	47.0	0.0	40.4	35.4	37.3
4	NC	GREENSBORO	42.0	0.0	37.0	30.7	33.4
4	NC	HIGHPOINT	44.0	0.0	38.2	34.8	36.6
4	NC	RALEIGH	46.0	0.0	40.1	34.4	36.4
4	NC	WILMINGTON	52.0	0.0	47.0	38.6	40.8
4	NC	WINSTON-SALEM	47.0	0.0	40.3	35.4	37.3
4	NC	OTHER URBAN AREAS	46.0	0.0	39.0	34.0	36.0
4	NC	AVE. FOR STATE	46.0	0.0	39.0	34.0	36.0
4	SC	CHARLESTON	47.0	0.0	40.7	35.6	37.5
4	SC	COLUMBIA	47.0	0.0	40.6	35.6	37.5
4	SC	GREENVILLE	46.0	0.0	39.8	34.7	36.6
4	SC	OTHER URBAN AREAS	46.7	0.0	40.2	35.3	37.2
4	SC	AVE. FOR STATE	46.7	0.0	40.2	35.3	37.2
4	TN	CHATTANOOGA	54.0	192.4	46.8	40.1	53.8
4	TN	KNOXVILLE	46.0	0.0	39.7	34.8	36.8
4	TN	MEMPHIS	48.0	0.0	43.6	34.8	38.8
4	TN	NASHVILLE	45.0	162.2	37.4	32.3	42.9
4	TN	OTHER URBAN AREAS	48.3	166.2	42.3	34.7	48.8
4	TN	AVE. FOR STATE	48.3	166.2	42.3	34.7	48.8
4		AVE. FOR REGION 4	49.6	161.0	44.9	37.2	45.5

TABLE V-10 WET-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL PRECP	WET-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
5	IL	AURORA	34.0	0.0	30.7	24.4	27.2
5	IL	BLOOMINGTON	36.0	0.0	32.2	26.1	29.2
5	IL	CHAMPAIGN	37.0	0.0	32.7	27.5	31.7
5	IL	CHICAGO	33.0	136.1	24.2	23.8	70.6
5	IL	DAVENPORT METRO	34.0	117.0	28.4	26.5	66.9
5	IL	DECATUR	37.0	123.0	0.0	29.9	80.2
5	IL	JOLIET	33.0	0.0	29.1	24.2	26.5
5	IL	PEORIA	35.0	115.3	0.0	28.0	69.2
5	IL	ROCKFORD	36.0	0.0	32.6	25.8	29.0
5	IL	SPRINGFIELD	35.0	124.0	30.1	26.3	49.4
5	IL	OTHER URBAN AREAS	35.0	133.8	26.3	24.6	64.6
5	IL	AVE. FOR STATE	35.0	133.8	26.3	24.6	64.6
5	IN	ANDERSON	36.0	106.1	0.0	0.0	106.1
5	IN	CHICAGO METRO	33.0	122.6	29.8	23.7	53.3
5	IN	EVANSVILLE	41.0	138.6	0.0	0.0	138.6
5	IN	FORT WAYNE	34.0	126.6	30.9	24.4	57.6
5	IN	INDIANAPOLIS	40.0	147.1	35.7	28.0	67.0
5	IN	LAFAYETTE	35.0	131.0	23.0	0.0	89.4
5	IN	MUNCIE	39.0	134.4	32.7	30.2	76.9
5	IN	SOUTH BEND	36.0	120.8	0.0	28.8	82.6
5	IN	TERRA HAUTE	41.0	0.0	34.8	32.0	32.9
5	IN	OTHER URBAN AREAS	37.2	128.4	31.5	26.3	68.8
5	IN	AVE. FOR STATE	37.2	128.4	31.5	26.3	68.8
5	MI	ANN ARBOR	31.0	0.0	26.7	23.3	25.7
5	MI	BAY CITY	28.0	93.7	0.0	22.8	63.3
5	MI	DETROIT	31.0	116.8	27.0	22.5	63.3
5	MI	FLINT	30.0	107.7	26.2	22.3	26.8
5	MI	GRAND RAPIDS	31.0	114.1	27.7	22.2	34.0
5	MI	JACKSON	34.0	114.4	0.0	26.6	64.9
5	MI	KALAMAZOO	34.0	0.0	29.8	24.9	26.8
5	MI	LANSING	31.0	110.9	26.9	23.1	47.8
5	MI	MUSKEGON	32.0	0.0	28.4	23.0	25.1
5	MI	SAGINAW	28.0	94.5	0.0	23.0	72.5
5	MI	OTHER URBAN AREAS	31.0	114.5	27.1	22.7	55.0
5	MI	AVE. FOR STATE	31.0	114.5	27.1	22.7	55.0
5	MN	DULUTH	29.0	104.3	25.3	21.0	36.2
5	MN	FARGO METRO	21.0	72.4	17.6	16.3	52.9
5	MN	MINNEAPOLIS	25.0	90.6	22.0	17.9	28.7
5	MN	ROCHESTER	29.0	0.0	24.6	22.1	23.9
5	MN	OTHER URBAN AREAS	26.0	90.5	22.3	18.2	30.3
5	MN	AVE. FOR STATE	26.0	90.5	22.3	18.2	30.3
5	OH	AKRON	38.0	0.0	34.1	27.3	30.2
5	OH	CANTON	38.0	144.6	34.3	27.2	35.4
5	OH	CINCINNATI	34.0	118.8	28.9	25.9	80.4
5	OH	CLEVELAND	32.0	124.3	30.2	21.8	41.3
5	OH	COLUMBUS	36.0	137.5	33.8	25.3	41.8
5	OH	DAYTON	35.0	0.0	31.2	25.4	28.1
5	OH	HAMILTON	40.0	150.3	36.5	24.1	55.0
5	OH	LIMA	38.0	115.9	0.0	0.0	119.9
5	OH	LORAIN	35.0	144.2	30.7	25.2	37.9
5	OH	MANSFIELD	43.0	0.0	35.9	25.5	34.1
5	OH	SPRINGFIELD	40.0	137.7	33.5	31.0	108.4
5	OH	STEUBENVILLE	40.0	140.1	0.0	0.0	120.3
5	OH	TOLEDO	32.0	116.5	27.9	23.5	50.1
5	OH	YOUNGSTOWN	42.0	152.0	36.9	20.8	68.3
5	OH	OTHER URBAN AREAS	37.2	125.3	31.9	24.8	49.3
5	OH	AVE. FOR STATE	37.2	125.3	31.9	24.8	49.3
5	WI	APPLETON	29.0	108.3	26.3	20.8	34.9
5	WI	DULUTH METRO	30.0	0.0	24.8	21.1	22.3
5	WI	GREEN BAY	27.0	94.6	23.0	20.4	25.0
5	WI	KENOSHA	32.0	118.7	26.6	0.0	42.3
5	WI	LA CROSSE	31.0	109.5	26.6	23.4	30.2
5	WI	MADISON	31.0	0.0	27.8	22.3	24.8
5	WI	MILWAUKEE	26.0	110.2	21.6	21.4	52.9
5	WI	OSHKOSH	28.0	0.0	23.4	0.0	23.4
5	WI	RACINE	32.0	0.0	25.5	24.1	26.6
5	WI	OTHER URBAN AREAS	29.7	116.2	23.7	21.4	31.1
5	WI	AVE. FOR STATE	29.7	116.2	23.7	21.5	31.1
5		AVE. FOR REGION 5.	32.7	124.0	27.8	23.5	52.8

TABLE V-10 WET-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	TN/YR ANNL PRECS	WET-WEATHER BOD (LBS/ACRE-YEAR)			
				COMB	STORM	UNSEW	AVER
6	AR	FORT SMITH	43.0	138.4	0.0	33.6	75.0
6	AR	LITTLE ROCK	49.0	0.0	42.6	37.9	39.1
6	AR	PINE BLUFF	52.0	0.0	44.3	39.7	42.0
6	AR	OTHER URBAN AREAS	48.0	138.4	43.2	37.2	48.1
6	AR	AVE. FOR STATE	48.0	138.4	43.2	37.2	48.1
6	LA	BATON ROUGE	60.0	0.0	52.6	44.5	48.3
6	LA	LAFAYETTE	59.0	0.0	50.2	45.0	47.6
6	LA	LAKE CHARLES	58.0	0.0	49.6	43.8	46.5
6	LA	MONROE	50.0	0.0	42.3	36.7	39.9
6	LA	NEW ORLEANS	64.0	0.0	61.9	0.0	61.9
6	LA	SHREVEPORT	45.0	0.0	38.5	34.1	36.0
6	LA	OTHER URBAN AREAS	56.0	0.0	55.1	40.0	49.9
6	LA	AVE. FOR STATE	56.0	0.0	55.1	40.0	49.9
6	NM	ALBUQUERQUE	9.0	0.0	7.9	6.6	7.2
6	NM	OTHER URBAN AREAS	9.0	0.0	7.9	6.6	7.3
6	NM	AVE. FOR STATE	9.0	0.0	7.9	6.6	7.2
6	OK	LAWTON	30.0	0.0	25.2	23.3	23.9
6	OK	OKLAHOMA CITY	31.0	0.0	27.8	21.8	24.0
6	OK	TULSA	37.0	0.0	32.8	26.6	29.1
6	OK	OTHER URBAN AREAS	32.7	0.0	29.4	23.6	25.8
6	OK	AVE. FOR STATE	32.7	0.0	29.4	23.6	25.8
6	TX	ABILENE	24.0	0.0	21.0	17.0	18.5
6	TX	AMARILLO	20.0	0.0	17.8	14.4	15.7
6	TX	AUSTIN	33.0	0.0	28.7	24.5	26.7
6	TX	BEAUMONT	54.0	198.1	48.1	[illegible]	[illegible]
6	TX	BROWNSVILLE	27.0	0.0	22.6	20.9	[illegible]
6	TX	BRYAN	39.0	0.0	34.8	27.5	[illegible]
6	TX	CORPUS CHRISTI	38.0	0.0	35.1	19.7	[illegible]
6	TX	DALLAS	35.0	0.0	31.8	24.2	27.2
6	TX	EL PASO	8.0	0.0	7.2	5.7	6.4
6	TX	FORT WORTH	30.0	0.0	26.8	21.1	23.3
6	TX	GALVESTON	43.0	205.2	0.0	32.4	47.1
6	TX	HARLINGEN	26.0	0.0	20.9	20.3	20.4
6	TX	HOUSTON	46.0	197.6	38.4	34.7	37.3
6	TX	LAREDO	19.0	0.0	16.2	14.5	15.5
6	TX	LUBBOCK	18.0	0.0	15.4	13.6	14.2
6	TX	MCALLEN	21.0	0.0	17.9	16.4	17.0
6	TX	MIDLAND	14.0	0.0	11.7	10.9	11.1
6	TX	ODESSA	14.0	0.0	11.9	10.7	11.4
6	TX	PORT ARTHUR	54.0	0.0	45.9	40.9	43.4
6	TX	SAN ANGELO	19.0	0.0	15.8	14.8	15.0
6	TX	SAN ANTONIO	28.0	0.0	25.3	20.1	22.9
6	TX	SHERMAN	39.0	0.0	31.8	30.4	30.7
6	TX	TEXARKANA	46.0	0.0	38.4	35.8	36.4
6	TX	TEXAS CITY	45.0	0.0	38.9	32.4	34.8
6	TX	TYLER	45.0	0.0	38.6	34.0	35.8
6	TX	WACO	32.0	0.0	28.1	22.8	24.7
6	TX	WICHITA FALL	29.0	0.0	24.4	22.5	23.2
6	TX	OTHER URBAN AREAS	31.0	200.1	29.7	24.3	27.5
6	TX	AVE. FOR STATE	31.0	200.1	29.7	24.3	27.5
6		AVE. FOR REGION 6	35.3	157.3	33.4	25.5	30.2

TABLE V-10 WET WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	TN/YR ANNL. PRECP	WET-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
7	IA	CEDAR RAPIDS	33.0	0.0	28.3	24.9	26.2
7	IA	DAVENPORT	34.0	121.8	29.6	24.7	37.8
7	IA	DES MOINES	31.0	134.1	23.9	22.4	37.2
7	IA	DUBUQUE	33.0	0.0	27.7	25.5	27.0
7	IA	SIOUX CITY	25.0	0.0	22.2	17.7	19.4
7	IA	WATERLOO	32.0	0.0	27.2	24.2	25.1
7	IA	OTHER URBAN AREAS	31.3	138.1	26.2	23.0	29.0
7	IA	AVE. FOR STATE	31.3	138.1	26.2	23.0	29.0
7	KS	KANSAS CITY METRO	34.0	121.6	29.6	25.3	46.8
7	KS	TOPEKA	34.0	122.3	29.7	25.1	48.0
7	KS	WICHITA	31.0	0.0	26.2	23.4	25.0
7	KS	OTHER URBAN AREAS	33.0	121.9	27.9	24.4	37.5
7	KS	AVE. FOR STATE	33.0	121.9	27.9	24.4	37.5
7	MO	COLUMBIA	37.0	0.0	32.6	26.3	28.6
7	MO	KANSAS CITY	34.0	127.6	26.4	25.7	45.5
7	MO	SPRINGFIELD	41.0	0.0	35.8	30.1	32.2
7	MO	ST.JOSEPH	35.0	107.7	0.0	0.0	107.7
7	MO	ST.LOUIS	37.0	127.0	0.0	30.7	98.3
7	MO	OTHER URBAN AREAS	36.8	125.2	29.2	28.5	70.3
7	MO	AVE. FOR STATE	36.8	125.2	29.2	28.5	70.3
7	NE	LINCOLN	27.0	0.0	23.9	19.7	21.7
7	NE	OMAHA	26.0	96.8	23.5	18.6	46.3
7	NE	OTHER URBAN AREAS	26.5	96.8	23.8	18.9	41.8
7	NE	AVE. FOR STATE	26.5	96.8	23.8	18.9	41.8
7		AVE. FOR REGION 7	31.9	121.7	27.0	25.0	50.2
8	CO	BOULDER	19.0	0.0	16.8	14.0	16.0
8	CO	COLORADO SPRINGS	13.0	0.0	11.2	9.8	10.3
8	CO	DENVER	14.0	60.9	12.5	10.1	11.5
8	CO	PUEBLO	12.0	47.5	10.0	9.1	13.4
8	CO	OTHER URBAN AREAS	14.5	50.2	12.4	10.1	11.6
8	CO	AVE. FOR STATE	14.5	50.2	12.4	10.1	11.6
8	MT	BILLINGS	13.0	0.0	11.2	9.8	10.4
8	MT	GREAT FALLS	15.0	0.0	12.6	11.5	12.2
8	MT	OTHER URBAN AREAS	14.0	0.0	12.0	10.5	11.3
8	MT	AVE. FOR STATE	14.0	0.0	12.0	10.5	11.3
8	ND	FARGO	21.0	73.5	17.9	16.1	19.0
8	ND	OTHER URBAN AREAS	21.0	73.5	17.9	16.1	19.0
8	ND	AVE. FOR STATE	21.0	73.5	17.9	16.1	19.0
8	SD	SIOUX FALLS	25.0	90.1	21.9	18.7	21.3
8	SD	OTHER URBAN AREAS	25.0	90.1	21.9	18.7	21.3
8	SD	AVE. FOR STATE	25.0	90.1	21.9	18.7	21.3
8	UT	OGDEN	17.0	0.0	15.0	12.4	13.5
8	UT	PROVO	13.0	0.0	11.6	9.2	10.1
8	UT	SALT LAKE CITY	15.0	0.0	13.2	10.8	12.0
8	UT	OTHER URBAN AREAS	15.0	0.0	13.4	10.9	12.0
8	UT	AVE. FOR STATE	15.0	0.0	13.4	10.9	12.0
8	WY	URBAN AREAS	15.0	0.0	12.9	11.3	12.0
8	WY	AVE. FOR STATE	15.0	0.0	12.9	11.3	12.0
8		AVE. FOR REGION 8	17.8	64.2	13.7	11.5	13.0

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TABLE V-10 WET WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	TN/YR ANNL. PRECP	WET WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
9	AK	URBAN AREAS	30.0	111.0	27.0	21.2	26.5
9	AK	AVE. FOR STATE	30.0	111.0	27.0	21.2	26.5
9	AZ	PHOENIX	7.0	0.0	6.2	5.0	5.5
9	AZ	TUCSON	11.0	0.0	9.5	8.3	8.9
9	AZ	OTHER URBAN AREAS	9.0	0.0	7.0	5.8	6.3
9	AZ	AVE. FOR STATE	9.0	0.0	7.0	5.8	6.3
9	CA	BAKERSFIELD	11.0	0.0	9.8	8.0	8.8
9	CA	FRESNO	11.0	0.0	9.4	8.2	8.9
9	CA	LOS ANGELES	13.0	0.0	11.5	9.6	11.1
9	CA	MODESTO	25.0	0.0	21.4	18.9	20.3
9	CA	OXNARD	15.0	0.0	13.4	10.8	11.8
9	CA	SACRAMENTO	18.0	45.2	15.5	13.1	17.9
9	CA	SALINAS	15.0	0.0	12.9	11.3	12.5
9	CA	SAN BERNARDINO	18.0	0.0	16.3	12.6	14.0
9	CA	SAN DIEGO	11.0	0.0	9.8	8.0	8.9
9	CA	SAN FRANCISCO	21.0	91.1	18.5	14.8	29.4
9	CA	SAN JOSE	14.0	0.0	12.7	10.1	11.8
9	CA	SANTA BARBARA	18.0	0.0	15.5	13.5	14.7
9	CA	SANTA ROSA	30.0	0.0	25.1	23.3	23.8
9	CA	SEASIDE	16.0	0.0	13.4	12.8	13.3
9	CA	SIMI VALLEY	25.0	0.0	21.4	18.9	19.9
9	CA	STOCKTON	14.0	0.0	12.1	10.5	11.4
9	CA	OTHER URBAN AREAS	17.2	88.7	12.5	11.5	14.9
9	CA	AVE. FOR STATE	17.2	88.7	12.5	11.5	14.9
9	HI	HONOLULU	23.0	0.0	20.6	16.7	18.8
9	HI	OTHER URBAN AREAS	23.0	0.0	20.6	16.7	18.8
9	HI	AVE. FOR STATE	23.0	0.0	20.6	16.7	18.8
9	NV	LAS VEGAS	4.0	0.0	3.5	2.9	3.1
9	NV	RENO	7.0	26.2	5.9	5.2	9.2
9	NV	OTHER URBAN AREAS	5.5	26.2	4.0	3.5	4.9
9	NV	AVE. FOR STATE	5.5	26.2	4.0	3.5	4.9
9		AVE. FOR REGION 9	16.9	86.8	12.4	10.9	14.2
10	ID	BOISE	11.0	0.0	9.3	8.5	8.9
10	ID	OTHER URBAN AREAS	11.0	0.0	9.3	8.5	8.9
10	ID	AVE. FOR STATE	11.0	0.0	9.3	8.5	8.9
10	OR	EUGENE	38.0	136.5	33.2	28.1	33.4
10	OR	PORTLAND	40.0	146.3	35.5	30.1	60.2
10	OR	SALEM	40.0	0.0	34.3	30.2	38.0
10	OR	OTHER URBAN AREAS	39.3	146.0	34.9	29.0	53.8
10	OR	AVE. FOR STATE	39.3	146.0	34.9	29.0	53.8
10	WA	SEATTLE	35.0	127.3	30.9	25.5	53.3
10	WA	SPOKANE	17.0	56.8	0.0	13.8	44.7
10	WA	TACOMA	39.0	141.1	34.3	28.6	33.0
10	WA	OTHER URBAN AREAS	30.3	103.9	32.1	25.3	48.3
10	WA	AVE. FOR STATE	30.3	103.9	32.1	25.3	48.3
10		AVE. FOR REGION 10	26.9	116.1	29.4	25.0	46.5
		AVERAGE FOR THE U.S.	33.4	136.6	30.5	25.9	43.6

TABLE V-11 DRY-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
1	CT	BRIDGEPORT	42.0	769.	769.	296.	516.
1	CT	BRISTOL	43.0	0.	857.	227.	448.
1	CT	DANBURY	42.0	0.	750.	247.	428.
1	CT	HARTFORD	42.0	823.	823.	278.	564.
1	CT	MERIDEN	45.0	0.	779.	240.	436.
1	CT	NEW BRITAIN	43.0	0.	702.	342.	552.
1	CT	NEW HAVEN	45.0	744.	744.	315.	546.
1	CT	NORWALK	44.0	2277.	276.	275.	503.
1	CT	STAMFORD	45.0	0.	745.	309.	508.
1	CT	WATERBURY	46.0	773.	773.	291.	507.
1	CT	OTHER URBAN AREAS	43.7	836.	736.	288.	521.
1	CT	AVE. FOR STATE	43.7	836.	736.	288.	521.
1	ME	LEWISTON	44.0	638.	0.	205.	414.
1	ME	PORTLAND	43.0	465.	0.	465.	465.
1	ME	OTHER URBAN AREAS	43.5	519.	0.	318.	444.
1	ME	AVE. FOR STATE	43.5	519.	0.	318.	444.
1	MA	BOSTON	43.0	982.	982.	226.	593.
1	MA	BROCKTON	45.0	0.	770.	296.	519.
1	MA	FALL RIVER	45.0	789.	789.	291.	544.
1	MA	FITCHBURG	46.0	761.	761.	244.	431.
1	MA	LAWRENCE	41.0	637.	0.	362.	493.
1	MA	LOWELL	40.0	864.	864.	252.	527.
1	MA	NEW BEDFORD	41.0	699.	699.	344.	509.
1	MA	PITTSFIELD	44.0	0.	788.	238.	439.
1	MA	SPRINGFIELD	45.0	480.	0.	480.	480.
1	MA	WORCESTER	46.0	1011.	685.	320.	526.
1	MA	OTHER URBAN AREAS	43.6	704.	931.	281.	554.
1	MA	AVE. FOR STATE	43.6	704.	931.	281.	554.
1	NH	MANCHESTER	40.0	630.	0.	305.	496.
1	NH	NASHUA	42.0	459.	0.	459.	459.
1	NH	OTHER URBAN AREAS	41.0	560.	0.	368.	481.
1	NH	AVE. FOR STATE	41.0	560.	0.	368.	481.
1	RI	PROVIDENCE	40.0	984.	721.	261.	546.
1	RI	OTHER URBAN AREAS	40.0	984.	721.	261.	546.
1	RI	AVE. FOR STATE	40.0	984.	721.	261.	546.
1	VT	URBAN AREAS	35.0	544.	0.	480.	509.
1	VT	AVE. FOR STATE	35.0	544.	0.	480.	509.
1		AVE. FOR REGION 1	41.1	700.	851.	290.	533.
2	NJ	ATLANTIC CITY	42.0	0.	864.	226.	471.
2	NJ	NEW YORK CITY METRO	43.0	2039.	944.	211.	517.
2	NJ	PHILADELPHIA METRO	43.0	615.	0.	109.	601.
2	NJ	TRENTON	42.0	0.	698.	345.	607.
2	NJ	VINELAND	44.0	0.	664.	271.	409.
2	NJ	AVE. FOR STATE	42.8	948.	921.	214.	520.
2	NY	ALBANY	38.0	873.	873.	253.	543.
2	NY	BINGHAMPTON	36.0	593.	0.	347.	543.
2	NY	BUFFALO	36.0	1041.	566.	301.	665.
2	NY	NEW YORK CITY	43.0	3879.	1730.	0.	2686.
2	NY	ROCHESTER	32.0	1045.	1045.	219.	601.
2	NY	SYRACUSE	38.0	749.	749.	318.	588.
2	NY	UTICA	44.0	780.	780.	311.	494.
2	NY	OTHER URBAN AREAS	38.1	2428.	1383.	272.	1533.
2	NY	AVE. FOR STATE	38.1	2428.	1383.	272.	1533.
2		AVE. FOR REGION 2	40.5	2284.	1126.	229.	979.

TABLE V-11 DRY-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	TN/YR ANNL. PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
3	DE	WILMINGTON	45.0	760.	760.	309.	553.
3	DE	OTHER URBAN AREAS	45.0	760.	760.	309.	553.
3	DE	AVE. FOR STATE	45.0	760.	760.	309.	553.
3	DC	WASHINGTON,D.C.	41.0	1950.	884.	0.	1243.
3	DC	AVE. FOR STATE	41.0	1950.	884.	0.	1243.
3	MD	BALTIMORE	43.0	0.	824.	301.	667.
3	MD	WASHINGTON DC METRO	41.0	0.	852.	274.	589.
3	MD	OTHER URBAN AREAS	42.0	0.	830.	292.	647.
3	MD	AVE. FOR STATE	42.0	0.	830.	292.	647.
3	PA	ALLENTOWN	44.0	837.	837.	276.	572.
3	PA	ALTOONA	44.0	701.	701.	343.	600.
3	PA	ERIE	38.0	723.	687.	344.	592.
3	PA	HARRISBURG	38.0	871.	871.	252.	535.
3	PA	JOHNSTOWN	45.0	619.	619.	406.	557.
3	PA	LANCASTER	43.0	690.	690.	351.	530.
3	PA	PHILADELPHIA	43.0	906.	785.	317.	690.
3	PA	PITTSBURGH	37.0	1313.	1313.	143.	536.
3	PA	READING	42.0	0.	699.	345.	599.
3	PA	SCRANTON	39.0	539.	0.	363.	476.
3	PA	WILKES-BARRE	39.0	746.	746.	309.	511.
3	PA	YORK	40.0	0.	660.	373.	550.
3	PA	OTHER URBAN AREAS	41.0	942.	834.	234.	608.
3	PA	AVE. FOR STATE	41.0	942.	834.	234.	608.
3	VA	LYNCHBERG	40.0	424.	0.	0.	424.
3	VA	NEWPORT NEWS	45.0	0.	792.	261.	464.
3	VA	NORFOLK	45.0	0.	902.	218.	464.
3	VA	PETERSBURG	43.0	0.	915.	218.	494.
3	VA	RICHMOND	44.0	783.	783.	345.	522.
3	VA	ROANOKE	42.0	697.	697.	345.	493.
3	VA	WASHINGTON DC METRO	41.0	994.	877.	0.	879.
3	VA	OTHER URBAN AREAS	42.9	660.	862.	254.	602.
3	VA	AVE. FOR STATE	42.9	660.	862.	254.	602.
3	WV	CHARLESTON	45.0	766.	766.	293.	503.
3	WV	HUNTINGTON	40.0	508.	0.	0.	508.
3	WV	STEUBENVILLE METRO	40.0	376.	0.	0.	376.
3	WV	WHEELING	39.0	622.	622.	406.	550.
3	WV	OTHER URBAN AREAS	41.0	555.	748.	320.	498.
3	WV	AVE. FOR STATE	41.0	555.	748.	320.	498.
3		AVE. FOR REGION 3	42.1	846.	838.	253.	622.

TABLE V-11 DRY-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
4	AL	BIRMINGHAM	53.0	0.	715.	330.	499.
4	AL	GADSDEN	55.0	0.	753.	286.	429.
4	AL	HUNTSVILLE	52.0	0.	767.	330.	428.
4	AL	MOBILE	68.0	0.	759.	367.	445.
4	AL	MONTGOMERY	54.0	0.	753.	385.	515.
4	AL	TUSCALOOSA	53.0	0.	611.	417.	460.
4	AL	OTHER URBAN AREAS	55.8	0.	732.	302.	473.
4	AL	AVE. FOR STATE	55.8	0.	732.	302.	473.
4	FL	FT.LAUDERDALE	60.0	0.	812.	275.	524.
4	FL	GAINESVILLE	58.0	0.	691.	351.	493.
4	FL	JACKSONVILLE	53.0	0.	758.	240.	483.
4	FL	MIAMI	60.0	0.	794.	304.	480.
4	FL	ORLANDO	51.0	882.	882.	229.	489.
4	FL	PENSACOLA	63.0	0.	779.	266.	502.
4	FL	ST.PETERSBURG	55.0	0.	671.	252.	438.
4	FL	TALLAHASSEE	57.0	0.	803.	274.	508.
4	FL	TAMPA	52.0	0.	923.	227.	519.
4	FL	WEST PALM BEACH	62.0	0.	756.	291.	478.
4	FL	OTHER URBAN AREAS	56.5	882.	812.	264.	533.
4	FL	AVE. FOR STATE	56.5	882.	812.	260.	533.
4	GA	ALBANY	48.0	393.	0.	0.	393.
4	GA	ATLANTA	47.0	710.	710.	345.	512.
4	GA	AUGUSTA	39.0	504.	0.	504.	504.
4	GA	COLUMBUS	49.0	687.	687.	350.	489.
4	GA	MACON	48.0	0.	786.	306.	500.
4	GA	SAVANNAH	52.0	955.	310.	285.	504.
4	GA	OTHER URBAN AREAS	46.5	609.	699.	349.	499.
4	GA	AVE. FOR STATE	46.5	609.	699.	349.	499.
4	KY	HUNTINGTON METRO	40.0	685.	685.	357.	493.
4	KY	LEXINGTON	44.0	0.	714.	339.	593.
4	KY	LOUISVILLE	41.0	883.	883.	256.	562.
4	KY	OWENSBORO	44.0	697.	697.	347.	621.
4	KY	OTHER URBAN AREAS	42.3	787.	837.	273.	566.
4	KY	AVE. FOR STATE	42.3	787.	837.	273.	566.
4	MS	BILOXI	58.0	0.	683.	352.	465.
4	MS	JACKSON	51.0	0.	737.	312.	508.
4	MS	OTHER URBAN AREAS	54.5	0.	719.	330.	490.
4	MS	AVE. FOR STATE	54.5	0.	719.	330.	490.
4	NC	ASHEVILLE	45.0	0.	852.	228.	465.
4	NC	CHARLOTTE	43.0	0.	686.	355.	508.
4	NC	DURHAM	43.0	0.	631.	412.	491.
4	NC	FAYETTEVILLE	47.0	0.	694.	347.	483.
4	NC	GREENSBORO	42.0	0.	778.	286.	499.
4	NC	HIGHPOINT	46.0	0.	593.	470.	460.
4	NC	RALEIGH	46.0	0.	747.	331.	479.
4	NC	WILMINGTON	52.0	0.	673.	322.	471.
4	NC	WINSTON-SALEM	47.0	0.	693.	348.	480.
4	NC	OTHER URBAN AREAS	46.0	0.	718.	339.	487.
4	NC	AVE. FOR STATE	44.0	0.	718.	339.	487.
4	SC	CHARLESTON	47.0	0.	694.	358.	488.
4	SC	COLUMBIA	47.0	0.	710.	348.	491.
4	SC	GREENVILLE	46.0	0.	694.	347.	483.
4	SC	OTHER URBAN AREAS	46.7	0.	697.	351.	488.
4	SC	AVE. FOR STATE	46.7	0.	697.	351.	488.
4	TN	CHATTANOOGA	54.0	721.	721.	316.	466.
4	TN	KNOXVILLE	46.0	0.	707.	343.	483.
4	TN	MEMPHIS	48.0	0.	878.	255.	554.
4	TN	NASHVILLE	45.0	760.	609.	253.	432.
4	TN	OTHER URBAN AREAS	48.3	755.	785.	277.	491.
4	TN	AVE. FOR STATE	48.3	755.	785.	277.	491.
4		AVE. FOR REGION 4	49.6	663.	766.	304.	507.

TABLE V-11 DRY-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
5	IL	AURORA	34.0	0.	868.	252.	532.
5	IL	BLOOMINGTON	36.0	0.	631.	275.	558.
5	IL	CHAMPAIGN	37.0	0.	791.	318.	609.
5	IL	CHICAGO	33.0	1338.	291.	272.	719.
5	IL	DAVENPORT METRO	34.0	611.	611.	421.	541.
5	IL	DECATUR	37.0	512.	0.	312.	512.
5	IL	JOLIET	33.0	0.	780.	291.	520.
5	IL	PEORIA	35.0	489.	0.	489.	489.
5	IL	ROCKFORD	36.0	0.	884.	253.	553.
5	IL	SPRINGFIELD	35.0	701.	701.	302.	565.
5	IL	OTHER URBAN AREAS	35.0	1236.	450.	295.	676.
5	IL	AVE. FOR STATE	35.0	1236.	450.	295.	676.
5	IN	ANDERSON	36.0	252.	0.	0.	252.
5	IN	CHICAGO METRO	33.0	870.	870.	257.	551.
5	IN	EVANSVILLE	41.0	558.	0.	0.	558.
5	IN	FORT WAYNE	34.0	879.	879.	252.	546.
5	IN	INDIANAPOLIS	40.0	832.	832.	213.	480.
5	IN	LAFAYETTE	35.0	800.	138.	0.	603.
5	IN	MUNCIE	39.0	615.	615.	406.	567.
5	IN	SOUTH BEND	36.0	537.	0.	491.	518.
5	IN	TERRA HAUTE	41.0	0.	620.	425.	502.
5	IN	OTHER URBAN AREAS	37.2	683.	775.	270.	508.
5	IN	AVE. FOR STATE	37.2	683.	775.	270.	508.
5	MI	ANN ARBOR	31.0	0.	699.	384.	592.
5	MI	BAY CITY	28.0	530.	0.	530.	530.
5	MI	DETROIT	31.0	925.	791.	272.	630.
5	MI	FLINT	30.0	746.	746.	316.	557.
5	MI	GRAND RAPIDS	31.0	834.	834.	254.	495.
5	MI	JACKSON	34.0	540.	0.	430.	490.
5	MI	KALAMAZOO	34.0	0.	760.	290.	476.
5	MI	LANSING	31.0	734.	734.	321.	539.
5	MI	MUSKEGON	32.0	0.	684.	260.	473.
5	MI	SAGINAW	28.0	552.	0.	552.	552.
5	MI	OTHER URBAN AREAS	31.0	875.	750.	290.	594.
5	MI	AVE. FOR STATE	31.0	875.	750.	290.	594.
5	MN	DULUTH	29.0	751.	751.	269.	442.
5	MN	FARGO METRO	21.0	616.	616.	406.	565.
5	MN	MINNEAPOLIS	25.0	780.	780.	254.	482.
5	MN	ROCHESTER	29.0	0.	653.	374.	580.
5	MN	OTHER URBAN AREAS	26.0	768.	771.	257.	492.
5	MN	AVE. FOR STATE	26.0	768.	771.	257.	492.
5	OH	AKRON	38.0	0.	846.	258.	510.
5	OH	CANTON	38.0	968.	845.	252.	580.
5	OH	CINCINNATI	34.0	658.	658.	374.	509.
5	OH	CLEVELAND	32.0	1054.	1054.	171.	532.
5	OH	COLUMBUS	36.0	980.	980.	221.	552.
5	OH	DAYTON	35.0	0.	821.	273.	534.
5	OH	HAMILTON	40.0	914.	914.	218.	494.
5	OH	LIMA	38.0	430.	0.	0.	430.
5	OH	LORAIN	38.0	1105.	764.	261.	460.
5	OH	MANSFIELD	40.0	0.	606.	418.	468.
5	OH	SPRINGFIELD	40.0	611.	611.	406.	578.
5	OH	STEUBENVILLE	40.0	665.	0.	0.	571.
5	OH	TOLEDO	32.0	797.	780.	296.	526.
5	OH	YOUNGSTOWN	42.0	775.	775.	296.	534.
5	OH	OTHER URBAN AREAS	37.2	778.	896.	287.	531.
5	OH	AVE. FOR STATE	37.2	778.	896.	287.	531.
5	WI	APPLETON	29.0	890.	890.	353.	562.
5	WI	DULUTH METRO	29.0	0.	650.	376.	407.
5	WI	GREEN BAY	27.0	666.	666.	358.	451.
5	WI	KENOSHA	32.0	865.	580.	0.	637.
5	WI	LA CROSSE	31.0	693.	693.	309.	507.
5	WI	MADISON	31.0	0.	843.	257.	528.
5	WI	MILWAUKEE	28.0	1461.	402.	378.	514.
5	WI	OSHKOSH	28.0	0.	608.	0.	608.
5	WI	RACINE	32.0	0.	698.	345.	605.
5	WI	OTHER URBAN AREAS	29.7	1324.	587.	351.	522.
5	WI	AVE. FOR STATE	29.7	1324.	587.	351.	522.
5		AVE. FOR REGION 5	32.7	942.	698.	279.	571.

TABLE V-11 DRY-WEATHER BOD LOADINGS

EPA RFG	STATE ID	URBANIZED AREA	TN/YR ANNL. PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER.
6	AR	FORT SMITH	43.0	430.	0.	430.	430.
6	AR	LITTLE ROCK	49.0	0.	736.	402.	491.
6	AR	PINE BLUFF	52.0	0.	665.	373.	524.
6	AR	OTHER URBAN AREAS	48.0	430.	712.	405.	482.
6	AR	AVE. FOR STATE	48.0	430.	712.	405.	482.
6	LA	BATON ROUGE	60.0	0.	748.	315.	526.
6	LA	LAFAYETTE	59.0	0.	662.	373.	537.
6	LA	LAKE CHARLES	58.0	0.	690.	352.	505.
6	LA	MONROE	50.0	0.	643.	408.	485.
6	LA	NEW ORLEANS	64.0	0.	1167.	0.	1167.
6	LA	SHREVEPORT	45.0	0.	686.	356.	499.
6	LA	OTHER URBAN AREAS	56.0	0.	961.	352.	749.
6	LA	AVE. FOR STATE	56.0	0.	961.	352.	749.
6	NM	ALBUQUERQUE	9.0	0.	786.	287.	506.
6	NM	OTHER URBAN AREAS	9.0	0.	786.	287.	506.
6	NM	AVE. FOR STATE	9.0	0.	786.	287.	506.
6	OK	LAWTON	30.0	0.	626.	414.	481.
6	OK	OKLAHOMA CITY	31.0	0.	849.	220.	455.
6	OK	TULSA	37.0	0.	801.	260.	474.
6	OK	OTHER URBAN AREAS	32.7	0.	815.	252.	464.
6	OK	AVE. FOR STATE	32.7	0.	815.	252.	464.
6	TX	ABILENE	24.0	0.	759.	232.	424.
6	TX	AMARILLO	20.0	0.	809.	258.	476.
6	TX	AUSTIN	33.0	0.	733.	320.	534.
6	TX	BEAUMONT	54.0	824.	824.	224.	445.
6	TX	BROWNSVILLE	27.0	0.	617.	406.	563.
6	TX	BRYAN	39.0	0.	824.	224.	445.
6	TX	CORPUS CHRISTI	28.0	0.	838.	222.	451.
6	TX	DALLAS	35.0	0.	846.	198.	470.
6	TX	EL PASO	8.0	0.	859.	240.	520.
6	TX	FORT WORTH	30.0	0.	849.	220.	454.
6	TX	GALVESTON	43.0	2258.	0.	344.	512.
6	TX	HARLINGEN	26.0	0.	503.	429.	441.
6	TX	HOUSTON	46.0	1552.	689.	351.	537.
6	TX	LAREDO	19.0	0.	661.	373.	541.
6	TX	LUBBOCK	18.0	0.	686.	351.	468.
6	TX	MCALLEN	21.0	0.	620.	422.	515.
6	TX	MIDLAND	14.0	0.	602.	419.	464.
6	TX	ODESSA	14.0	0.	660.	373.	547.
6	TX	PORT ARTHUR	54.0	0.	660.	359.	448.
6	TX	SAN ANGELO	19.0	0.	603.	418.	464.
6	TX	SAN ANTONIO	28.0	0.	681.	255.	559.
6	TX	SHERMAN	39.0	0.	540.	426.	447.
6	TX	TEXARKANA	46.0	0.	602.	419.	464.
6	TX	TEXAS CITY	45.0	0.	704.	259.	417.
6	TX	TYLER	45.0	0.	691.	351.	494.
6	TX	WACO	32.0	0.	769.	242.	433.
6	TX	WICHITA FALL	29.0	0.	631.	412.	490.
6	TX	OTHER URBAN AREAS	31.0	1228.	766.	278.	496.
6	TX	AVE. FOR STATE	31.0	1228.	766.	278.	496.
6		AVE. FOR REGION 6.	35.3	675.	803.	291.	520.

TABLE V-11 DRY-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNUAL PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
7	IA	CEDAR RAPIDS	33.0	0.	692.	348.	478.
7	IA	DAVENPORT	34.0	738.	738.	273.	436.
7	IA	DES MOINES	31.0	1427.	364.	267.	490.
7	IA	DUBUQUE	33.0	0.	620.	406.	556.
7	IA	SIOUX CITY	25.0	0.	613.	234.	448.
7	IA	WATERLOO	32.0	0.	665.	358.	450.
7	IA	OTHER URBAN AREAS	31.3	1743.	612.	299.	473.
7	IA	AVE. FOR STATE	31.3	1743.	612.	299.	473.
7	KS	KANSAS CITY METRO	34.0	734.	734.	321.	541.
7	KS	TOPEKA	34.0	752.	752.	305.	498.
7	KS	WICHITA	31.0	0.	695.	347.	522.
7	KS	OTHER URBAN AREAS	33.0	741.	714.	328.	525.
7	KS	AVE. FOR STATE	33.0	741.	714.	328.	525.
7	MO	COLUMBIA	37.0	0.	784.	239.	438.
7	MO	KANSAS CITY	34.0	911.	409.	358.	473.
7	MO	SPRINGFIELD	41.0	0.	750.	292.	469.
7	MO	ST. JOSEPH	35.0	332.	0.	0.	332.
7	MO	ST. LOUIS	37.0	604.	0.	592.	599.
7	MO	OTHER URBAN AREAS	36.8	621.	529.	465.	537.
7	MO	AVE. FOR STATE	36.8	621.	529.	465.	537.
7	NE	LINCOLN	27.0	0.	803.	285.	526.
7	NE	OMAHA	26.0	880.	880.	252.	546.
7	NE	OTHER URBAN AREAS	26.5	880.	833.	260.	541.
7	NE	AVE. FOR STATE	26.5	880.	833.	260.	541.
7		AVE. FOR REGION 7	31.9	712.	657.	367.	520.
8	CO	BOULDER	19.0	0.	802.	306.	655.
8	CO	COLORADO SPRINGS	13.0	0.	696.	346.	487.
8	CO	DENVER	14.0	1635.	834.	267.	560.
8	CO	PUEBLO	12.0	1138.	591.	350.	543.
8	CO	OTHER URBAN AREAS	14.5	1238.	798.	290.	555.
8	CO	AVE. FOR STATE	14.5	1238.	798.	290.	555.
8	MT	BILLINGS	13.0	0.	693.	349.	508.
8	MT	GREAT FALLS	15.0	0.	629.	388.	544.
8	MT	OTHER URBAN AREAS	14.0	0.	657.	364.	525.
8	MT	AVE. FOR STATE	14.0	0.	657.	364.	525.
8	ND	FARGO	21.0	662.	662.	384.	563.
8	ND	OTHER URBAN AREAS	21.0	642.	662.	384.	563.
8	ND	AVE. FOR STATE	21.0	642.	662.	384.	563.
8	SD	SIOUX FALLS	25.0	759.	759.	328.	516.
8	SD	OTHER URBAN AREAS	25.0	759.	759.	328.	516.
8	SD	AVE. FOR STATE	25.0	759.	759.	328.	516.
8	UT	OGDEN	17.0	0.	777.	287.	497.
8	UT	PROVO	13.0	0.	813.	234.	448.
8	UT	SALT LAKE CITY	15.0	0.	749.	276.	506.
8	UT	OTHER URBAN AREAS	15.0	0.	790.	271.	495.
8	UT	AVE. FOR STATE	15.0	0.	790.	271.	495.
8	WY	URBAN AREAS	15.0	0.	693.	349.	506.
8	WY	AVE. FOR STATE	15.0	0.	693.	349.	506.
8		AVE. FOR REGION 8	17.4	988.	760.	303.	532.

TABLE V-11 DRY-WEATHER BOD LOADINGS

EPA REG	STATE ID	URBANIZED AREA	IN/YR ANNL. PRECP	DRY-WEATHER BOD (LBS/ACRE-YEAR) COMB	STORM	UNSEW	AVER
9	AK	URBAN AREAS	30.0	854.	854.	227.	466.
9	AK	AVE. FOR STATE	30.0	854.	854.	227.	466.
9	AZ	PHOENIX	7.0	0.	777.	206.	484.
9	AZ	TUCSON	11.0	0.	715.	340.	518.
9	AZ	OTHER URBAN AREAS	9.0	0.	761.	268.	492.
9	AZ	AVE. FOR STATE	9.0	0.	761.	268.	492.
9	CA	BAKERSFIELD	11.0	0.	822.	273.	535.
9	CA	FRESNO	11.0	0.	735.	321.	550.
9	CA	LOS ANGELES	13.0	0.	789.	316.	552.
9	CA	MODESTO	25.0	0.	690.	350.	537.
9	CA	OXNARD	15.0	0.	819.	256.	482.
9	CA	SACRAMENTO	18.0	776.	776.	282.	506.
9	CA	SALINAS	15.0	0.	698.	345.	602.
9	CA	SAN BERNARDINO	18.0	0.	873.	217.	464.
9	CA	SAN DIEGO	11.0	0.	815.	277.	539.
9	CA	SAN FRANCISCO	21.0	1619.	842.	183.	619.
9	CA	SAN JOSE	14.0	0.	886.	258.	574.
9	CA	SANTA BARBARA	18.0	0.	701.	342.	562.
9	CA	SANTA ROSA	30.0	0.	613.	417.	469.
9	CA	SEASIDE	16.0	0.	609.	406.	585.
9	CA	SIMI VALLEY	25.0	0.	687.	354.	487.
9	CA	STOCKTON	14.0	0.	702.	342.	555.
9	CA	OTHER URBAN AREAS	17.2	1539.	798.	262.	617.
9	CA	AVE. FOR STATE	17.2	1539.	798.	262.	617.
9	HI	HONOLULU	23.0	0.	841.	277.	583.
9	HI	OTHER URBAN AREAS	23.0	0.	841.	277.	583.
9	HI	AVE. FOR STATE	23.0	0.	841.	277.	583.
9	NV	LAS VEGAS	4.0	0.	801.	258.	469.
9	NV	RENO	7.0	893.	661.	326.	508.
9	NV	OTHER URBAN AREAS	5.5	893.	777.	277.	480.
9	NV	AVE. FOR STATE	5.5	893.	777.	277.	480.
9		AVE. FOR REGION 9	16.9	1507.	797.	263.	601.
10	ID	BOISE	11.0	0.	657.	405.	526.
10	ID	OTHER URBAN AREAS	11.0	0.	657.	405.	526.
10	ID	AVE. FOR STATE	11.0	0.	657.	405.	526.
10	OR	EUGENE	38.0	748.	748.	306.	502.
10	OR	PORTLAND	40.0	811.	811.	276.	535.
10	OR	SALEM	40.0	0.	690.	352.	501.
10	OR	OTHER URBAN AREAS	39.3	810.	780.	288.	528.
10	OR	AVE. FOR STATE	39.3	810.	780.	288.	528.
10	WA	SEATTLE	35.0	791.	791.	282.	530.
10	WA	SPOKANE	17.0	527.	0.	527.	527.
10	WA	TACOMA	39.0	774.	774.	290.	504.
10	WA	OTHER URBAN AREAS	30.3	703.	785.	302.	525.
10	WA	AVE. FOR STATE	30.3	703.	785.	302.	525.
10		AVE. FOR REGION 10	26.9	734.	763.	307.	526.
		AVERAGE FOR THE U.S.	33.4	1039.	807.	285.	594.

ABBREVIATIONS AND SYMBOLS

a	Coefficient
A_i	Area of land use i
AR	Wet-weather runoff, inches per year
α	Normalized pollutant loading factor for separate sewered areas, pounds per acre-inch
b	Coefficient
BOD	Biochemical oxygen demand
BOD_5	Biochemical oxygen demand at five days
β	Normalized pollutant loading factor for combined sewered areas, pounds per acre-inch
C	Concentration, mass pollutant per total mass or mg/l
COD	Chemical oxygen demand
com	Abbreviation for commercial
CR	Runoff coefficient
dd_i	Pounds of accumulated dust and dirt (or "surface solids") on land use i per curb-mile - dry day
DD_i	Dust and dirt loading for land use i, pounds per day
ε	Street sweeping efficiency
DWF	Abbreviation for dry-weather flow and dry-weather flow runoff, inches per year
f_1	Factor for adjustment of pollutant loads, a function of precipitation
f_2	Factor for adjustment of pollutant loads, a function of population density
f_3	Factor for adjustment of pollutant loads, a function of street sweeping interval
$F_{i,j}$	Fraction of dust and dirt on land use i that consists of pollutant j
$G_{1,i}$	Length of curb per area of land use i, curb-miles per acre

γ	Street sweeping factor
I	Imperviousness as a fraction or percent
K	Conversion factor
m	Coefficient
M	Pollutant loading, pounds per acre-year
$\overline{M}$	Pollutant loading averaged over different land uses, pounds per acre-year
M_c	Pollutant loading in combined sewered areas, pounds per acre-year
M_{Dw}	Pollutant loading under dry weather conditions, pounds per acre-year
M_s	Pollutant loading in separate sewered areas, pounds per acre-year
n	Number of storms per year, also number of times street swept since last storm
N	Total nitrogen
N_D	Number of dry days since last storm
N_s	Street sweeping interval, days
P	Precipitation rate, inches per year
P_o	Mass of pollutant on surface at end of previous storm, pounds
$P_{i,j}$	Mass of pollutant j on surface of land use i at beginning of storm, pounds
P_s	Precipitation depth during one storm, inches
PD	Population density, persons per acre
PD_d	Population density in developed area, persons per acre
PO_4	Phosphate or total phosphate
r	Correlation coefficient
res	Abbreviation for residential
ρ	Water density, pounds per cubic foot

SS	Suspended solids
TOC	Total organic carbon
TPO_4	Total phosphate
TS	Total solids
VS	Total volatile solids
w_i	Fraction of total area consisting of land use i

REFERENCES

1. American Public Health Association, American Public Works Association, Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater, 13th Edition, American Public Health Association, Washington, DC, 1971.

2. Colston, N. V., "Characterization and Treatment of Urban Land Runoff," USEPA Report EPA-670/2-74-096, NTIS-PB 240 987, December 1974.

3. Metcalf and Eddy, Inc., University of Florida, and Water Resources Engineers, Inc., "Storm Water Management Model, Volume I - Final Report," USEPA Report 11024DOC07/71, NTIS-PB 203 289, September 1971.

4. Huber, W. C., Heaney, J. P., et al., "Storm Water Management Model User's Manual Version II," USEPA Report EPA-670/2-75-017, March 1975.

5. Hydrologic Engineering Center, Corps of Engineers, "Urban Storm Water Runoff: STORM," Generalized Computer Program 723-58-L2520, May 1975.

6. Roesner, L. A., et al., "A Model for Evaluating Runoff-Quality in Metropolitan Master Planning," ASCE Urban Water Resources Research, Program, Technical Memo No. 23, ASCE, New York, NY, April 1974.

7. APWA, "Water Pollution Aspects of Urban Runoff," USEPA Report 11030DNS01/69 (WP-20-15), NTIS-PB 215 532, January 1969.

8. Graham, P. H., Costello, L. S. and Mallon, H. J., "Estimation of Imperviousness and Specific Curb Length for Forecasting Stormwater Quality and Quantity," JWPCF, Vol. 46, No. 4, pp. 717-725, April 1974.

9. AVCO Economic Systems Corporation, "Storm Water Pollution from Urban Land Activity," USEPA Report 11034FKO7/70, NTIS-PB 195 281, July 1970.

10. Burgess and Niple, Ltd., "Stream Pollution and Abatement from Combined Sewer Overflows, Bucyrus, Ohio," USEPA Report 11024FKN11/69, NTIS-PB 195 162, November 1969.

11. Black, Crow and Eidsness, Inc., "Storm and Combined Sewer Pollution Sources and Abatement, Atlanta, Georgia," USEPA Report 11024ELB01/71, NTIS-PB 201 725, January 1971.

12. Hayes, Seay, Mattern and Mattern, "Engineering Investigation of Sewer Overflow Problem," USEPA Report 11024DMS05/70, NTIS-PB 195 201, May 1970.

13. Rex Chainbelt, Inc., "Screening/Flotation Treatment of Combined Sewer Overflows," USEPA Report 11020FDC01/72, January 1972.

14. Roy F. Weston, Inc., "Combined Sewer Overflow Abatement Alternatives, Washington, DC," USEPA Report 11024EXF08/70, NTIS-PB 203 680, August 1970.

15. Davis, P. L. and Borchardt, F., "Combined Sewer Overflow Abatement Plan, Des Moines, Iowa," USEPA Report EPA-R2-73-170, April 1973.

16. Weibel, S. R., Anderson, R. J. and Woodward, R. L., "Urban Land Runoff as a Factor in Stream Pollution," JWPCF, Vol. 36, No. 7, pp. 914-924, July 1969.

17. Bryan, E. H., "Quality of Stormwater Drainage from Urban Land Areas in North Carolina," Report No. 37, Water Resources Research Institute, University of North Carolina, Raleigh, 1970.

18. Cornell, Howland, Hayes and Merryfield-Hill, Inc., "A Water Resources Management Program, Vol. V. User's Manual: The Hydrocomp Simulation Program for Water Quality," Appendix E, Land Washoff Parameters, Report for Municipality of Metropolitan Seattle, 1975.

19. Droste, R. L., "Pollution Loadings of Urban Storm Runoff," M. Appl. Sc. Thesis, Department of Civil Engineering, University of Windsor, Windsor, Ontario, July 1974.

20. Lager, J. A. and Smith, W. G., "Urban Stormwater Management and Technology: An Assessment," USEPA Report EPA-670/2-74-040, NTIS-PB 240 687, December 1974.

21. Stankowski, S. J., Magnitude and Frequency of Floods in New Jersey with Effects of Urbanization, Special Report 38, US Geological Survey Water Resources Division, Trenton, NJ, 1974.

22. Waller, D. H., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewage Systems," Central Mortgage and Housing Corporation, Ottawa, Ontario, April 1971.

23. American Public Works Association and University of Florida, "Evaluation of the Magnitude and Significance of Pollution Loading from Urban Stormwater Runoff - Ontario," Environmental Protection Service and Ontario Ministry of Environment, Toronto, 1976.

24. Pisano, W. C., "Cost Effective Approach for Combined and Storm Sewer Clean-Up" in "Proceedings, Urban Stormwater Management Seminars," USEPA Report WPD 03-76-04, January 1976.

SECTION VI

OVERALL COST ASSESSMENT

This section develops and applies a methodology to estimate the cost of controlling pollution from urban storm-related discharges nationwide. Costs of controlling combined sewer overflows, stormwater runoff, and/or providing tertiary treatment are compared.

BACKGROUND

In 1967, the APWA conducted a survey to gain information related to wet-weather pollution.[1] All urban communities with a population greater than 25,000 persons were involved. Results indicated that approximately $56 billion (1974 dollars) would be needed to complete separation of all existing combined sewers. An additional $34 billion (1974 dollars) in plumbing changes on private property would be required to effect the separation. These costs do not include any indirect costs brought about by the disruption in a dense urban area which would occur if the separation actually took place.

In 1973 and 1974, USEPA conducted "Needs" surveys to estimate the costs to meet the requirements and goals set forth in the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). The surveys were sent to each state and, on the basis of the reported figures, a total cost was estimated. A review of the results of the surveys shows how little attention has been given to developing quantity and quality criteria by which the cost of controlling wet-weather pollution could be assessed.[2] Due to a lack of guidelines which the states could follow and the short time available, some states elected to use only USEPA guidelines. Those states that did make their own assessments went by their own criteria and are therefore not comparable on an equal basis. The reported needs for Category VI (Treatment and/or Control of Stormwater) of the 1974 Needs Survey were greater than the cost of all other categories combined. Reported costs included construction of storm sewers and elements of flood control.

The next part of this section presents a general methodology for determining wet-weather pollution control costs. Then, a procedure is described for determining the relationship between storage, treatment, and pollutant control for control of wet-weather flows. Generalized predictive equations are developed based on relatively intensive studies of five cities: Atlanta, Denver, Minneapolis, San Francisco, and Washington. Knowing this "production function" one can determine the optimal combination of storage and treatment by combining this information with data on the cost and performance of the available control options. This information is combined to produce the national assessment. Results are presented for all

1. urbanized areas in the US,

2. states, and

3. USEPA regions.

METHODOLOGY

There are several economic theories which, when applied to environmental resources management, assist in the decision-making process. One such theory is production theory, which provides techniques that aid in evaluating items such as the optimal size of a reservoir for water supply and flood control, or a wastewater treatment plant for pollution control. When the cost of inputs such as the reservoir or treatment plant is known then the cost of achieving a desired level of output (e.g., water supply or pollution control) may be determined.

In stormwater management, the inputs may be in the form of a storage capacity and a treatment rate. Storage is expressed in terms of million gallons or inches over a certain area, typically the watershed being analyzed. The unit for treatment is either million gallons per day or inches per hour, using the same area as storage.

When the degree of wet-weather control is considered as a single output, it can be expressed either in terms of the percent of the runoff treated or the number of overflows per year. This is with respect to quantity only and is therefore dependent upon the input storage capacity and treatment rate.

When dealing with only two inputs it is feasible to use a graphical method to find the optimal combinations. Isoquants can be constructed which represent equal levels of output for different combinations of input (see Figure VI-1, Determination of Least-Cost Combination of Inputs). For example, each isoquant could represent a specific percent of the runoff treated for different combinations of storage and treatment. Isoquants have the following properties:[3]

1. Two isoquants cannot intersect. Intersecting isoquants would imply two different levels of output from the same input.

2. Isoquants slope downward and to the right because as one input increases it takes less of the other input to achieve the same level of output.

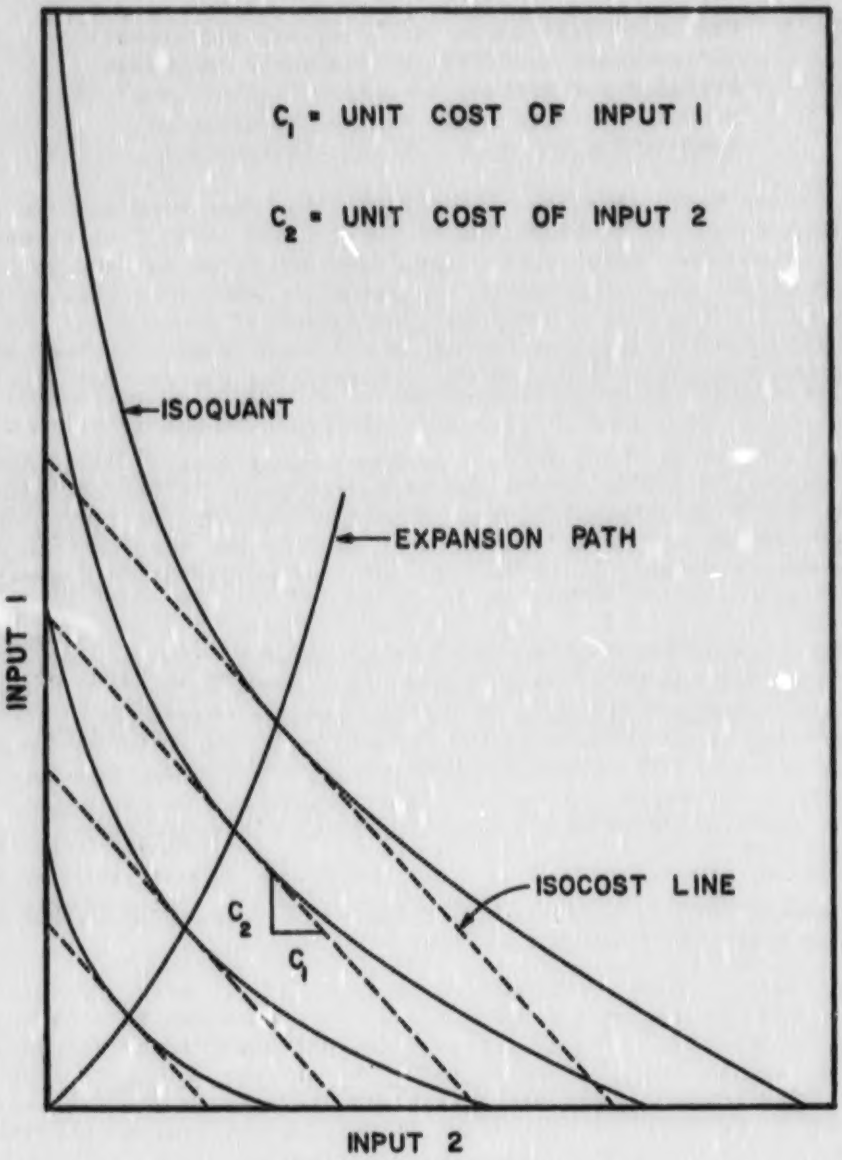
C_1 = UNIT COST OF INPUT 1
C_2 = UNIT COST OF INPUT 2
ISOQUANT
EXPANSION PATH
INPUT 1
ISOCOST LINE
C_2
C_1
INPUT 2

Figure VI-1. Determination of Least-Cost Combination of Inputs

3. Isoquants are convex to the origin because of the decreasing ability of one input to be substituted for another to obtain a given level of output. This is known as the principle of diminishing marginal rate of substitution.

Also on Figure VI-1, a series of parallel lines has been constructed. These lines represent combinations of input 1 and input 2 which may be achieved at the same total cost. The lines are known as isocost lines. The slope of the isocost lines is the relative unit cost between input 1 and input 2. The most economical combination of input 1 and input 2 to produce a desired level of output is the point where the isocost lines become tangent to the isoquant representing the desired level of output.

The line which joins the points of tangency among several isoquants and the isocost lines is called the expansion path. After the expansion path has been determined, the optimal combination of inputs can be determined for any level of output by finding the intersection of the isoquant representing the desired level of output and the expansion path.

The maximum output for a given cost may be found by constructing the isocost line for the given total expenditure. The slope of the isocost line is the relative unit cost of the two inputs. The intercept of the axis depicting input 1 would be the allowed total cost divided by the unit cost of input 1. From this information, the isocost line may be drawn. The point where the isocost line intersects the expansion path gives the combination of inputs which produces the maximum output at the given cost.

The stormwater quality management problem can be expressed in the more compact mathematical form shown below:

minimize

$$Z = c_S(S) + c_T(T) \tag{VI-1}$$

subject to

$$f(R_1;S,T) = 0$$

$$R_1,S,T \geq 0$$

where Z = total control costs,

$c_S(S)$ = storage costs,

$c_T(T)$ = treatment costs,

S = storage volume,

T = treatment rate,

R_1 = percent pollutant control, and

$f(R_1;S,T)$ = production function relating the level of pollutant control (R_1) attainable with specified availabilities of storage (S) and treatment (T).

The next three subsections describe

- the available storage/treatment options - their costs and effectiveness;
- the production functions for evaluating tradeoffs between storage and treatment; and
- the solution to the optimization problem yielding the optimal expansion path for any city.

Given this information, the final assessment is presented.

CONTROL TECHNOLOGY AND ASSOCIATED COSTS

A wide variety of control alternatives are available for improving the quality of wet-weather flows.[4,5,6] Rooftops and parking lot storage, surface and underground tanks and storage in treatment units are the flow attenuation control alternatives. Wet-weather quality control alternatives can be subdivided into two categories: primary devices and secondary devices. Primary devices take advantage of physical processes such as screening, settling and flotation. Secondary devices take advantage of biological processes and physical-chemical processes. These control devices are suitable for treating stormwater runoff as well as combined sewer overflows. However, the contact stabilization process is feasible only if the existing waste treatment plant is of an activated sludge type. The quantities of wet-weather flows that can be treated by this process are limited by the amount of excess activated sludge available from the dry-weather plant. At the present time, there are several installations throughout the US designed to evaluate the effectiveness of various primary and secondary devices. A summary of the design criteria and performance of these devices is presented in Table VI-1, Wet-Weather Treatment Plant Performance Data. Based on these data, the representative performance of primary devices is assumed to be 40 percent BOD_5 removal efficiency and that of secondary devices to be 85 percent BOD_5 removal efficiency.

Table VI-1. WET-WEATHER TREATMENT PLANT PERFORMANCE DATA

Device	Control Alternatives	Design Criteria gpm/sq ft (l/min-m^2)	Reported BOD_5 Removal Efficiency, η
Primary	Swirl Concentrator[a,b]	60.0 (2,448.0)	0.25 - 0.50
	Microstrainer[c]	20.0 (816.0)	0.40 - 0.60
	Dissolved Air Flotation w/ Chemical Addition[d]	2.5 (102.0)	0.50 - 0.60
	Sedimentation[e]	0.5 (20.4)	0.25 - 0.40
	Representative Performance		0.40
Secondary	Contact Stabilization[f]		0.75 - 0.88
	Physical-Chemical[g]		0.85 - 0.95
	Representative Performance		0.85

[a] Field, 1976.[7]

[b] Sullivan, 1974.[8]

[c] Maher, 1974.[9]

[d] Lager and Smith, 1974.[5]

[e] Performance data based on domestic wastewater treatment.

[f] Agnew _et al._, 1975.[10]

[g] Estimate based on performance of these units for domestic wastewater.

"Storage" devices will typically be used in conjunction with the above "treatment" devices. The two purposes are interrelated. Wastewater detained a sufficient time in a storage unit will undergo treatment. On the other hand, treatment units also function as storage units in that they equalize fluctuations in influent flow and concentration. DiToro presents approaches for evaluating the equalization and treatment which occur in both of these units.[11] The STORM model, which was used in this assessment, assumes the configuration for storage and treatment shown in Figure VI-2, Storage-Treatment Configuration Used in STORM Model. No treatment is assumed to occur in storage and "treatment" is assumed to be complete removal of all pollutants routed through treatment. Thus, for the purposes of this assessment, no treatment is assumed to occur in storage and control costs are assigned accordingly. This assumption tends to underestimate the costs of storage since all provisions for solids handling are included in treatment.

Cost data for installed wet-weather treatment devices are listed in Table VI-2, Installed Costs for Wet-Weather Treatment Devices. Since wet-weather control facilities operate intermittently, annual operation and maintenance costs are greatly affected by the number of hours the facility is utilized. As a general rule, a facility will operate a greater amount of the time if it incorporates storage. An examination of Table VI-2 reveals that annual operation and maintenance costs are 16.7 percent of the total annual costs for the contact stabilization unit. In the case of the swirl concentrator, the percentage is 27.3. Annual operation and maintenance costs for other units fall in between these two values. Based on this analysis, it was decided to assume annual operation and maintenance costs as 20 percent of the total annual costs for all treatment devices. Cost functions developed for various wet-weather quality control devices are presented in Table VI-3, Cost Functions for Wet-Weather Control Devices. These costs include provisions for sludge handling, engineering, contingencies and land costs.

All treatment units exhibit economies of scale, i.e., unit costs decrease as plant size increases. Thus, there is an incentive to build larger units. The optimal size treatment unit can be found by comparing the savings in treatment cost of going to a larger unit with the increased piping costs. For example, if one is considering building two 10 mgd (37,850 m^3/day) plants with building one 20 mgd (75,700 m^3/day) plant and a pipeline, the breakeven pipe length, L, is found using

$$\begin{array}{cc} \text{Two plants} & \text{One plant + pipeline} \\ s(10)^z + s(10)^z & = s(20)^z + K(10)^y(L) \end{array} \qquad \text{(VI-2)}$$

where s, z, K and y = coefficients.

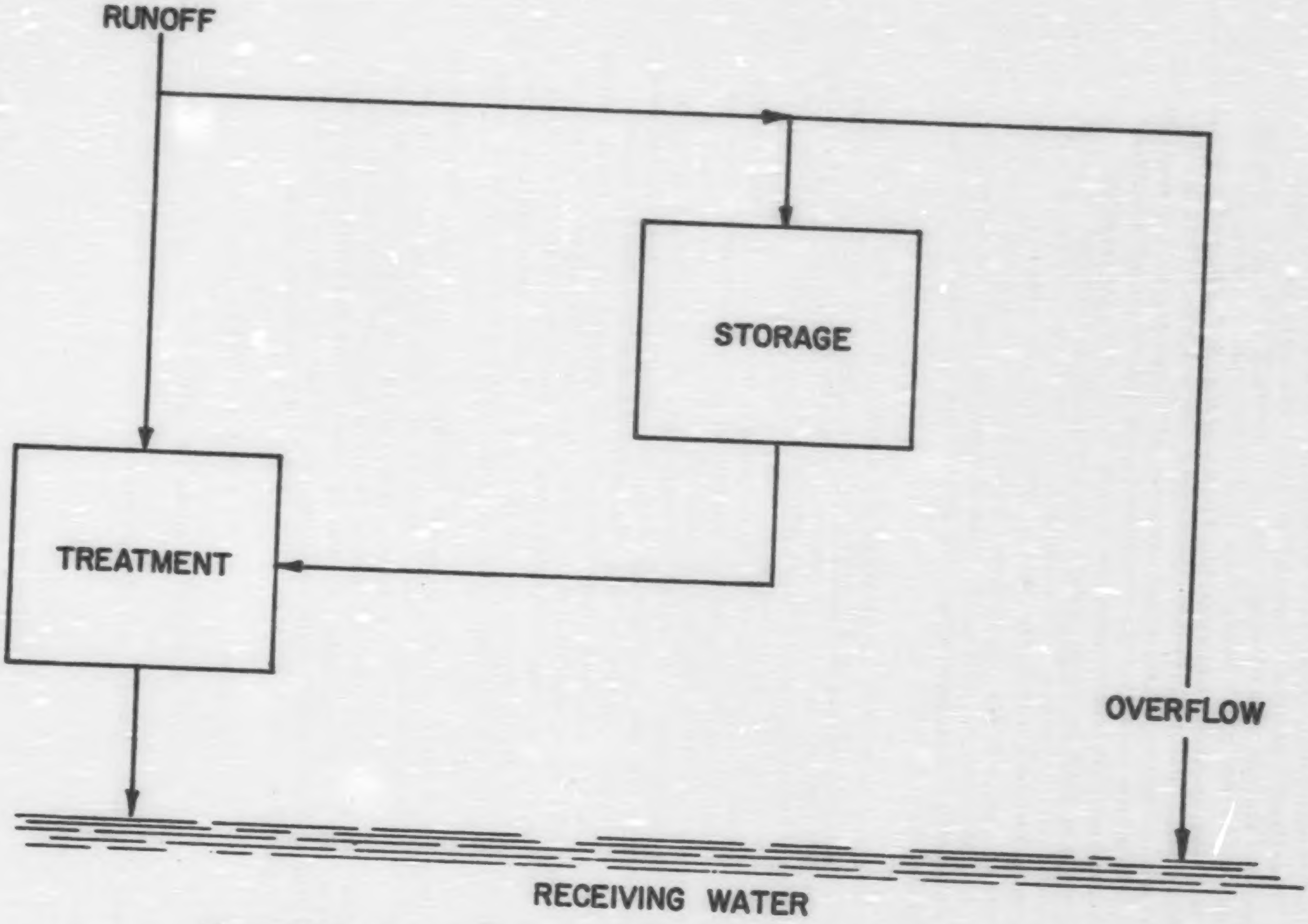
RUNOFF
STORAGE
TREATMENT
OVERFLOW
RECEIVING WATER

Figure VI-2. Storage-Treatment Configuration Used in STORM Model

Table VI-2. INSTALLED COSTS FOR WET-WEATHER TREATMENT DEVICES

		Annual Cost: $/yr		
Control Device	Capacity mgd (m^3/day)	Amortized Capital[a,b]	Operation and Maintenance	Total
Swirl Concentrator[c]	6.8 (26,400)	5,600	2,100	7,700
Microstrainer[d]	7.4 (28,700)	14,230	3,895	18,125
Dissolved Air Flotation[e]	25.0 (96,900)	71,706	16,700[f]	88,406
Contact Stabilization[g]	20.0 (77,500)	120,000	24,000	144,000

[a] Based on 8 percent interest for 20 years.

[b] Construction cost. Does not include sludge handling costs.

[c] Field, 1976.[7]

[d] Maher, 1974.[9]

[e] Lager and Smith, 1974[8] for Racine, Wisconsin adjusted to ENR = 2200.

[f] Operation and maintenance costs based on 480 hours of operation @ $0.0341/1,000 gallons ($0.0126 per 1,000 l).

[g] Agnew et al., 1975.[10] Operation and maintenance costs based on 960 hours of operation.

Table VI-3. COST FUNCTIONS FOR WET-WEATHER CONTROL DEVICES

		Annual Cost: $/yr					
		Amortized Capital		Operation and Maintenance		Total	
		$CA = lT^m$ or lS^m		$OM = pT^q$		$TC = sT^z$ or sS^z	
Device	Control Alternative	l	m	p	q	s	z
Primary	Swirl Concentrator[c,d,e]	1,971.0	0.70	493.0	0.70	2,464.0	0.70
	Microstrainer[e,f]	7,343.8	0.76	1,836.0	0.76	9,179.8	0.76
	Dissolved Air Flotation	8,161.4	0.84	2,036.7	0.84	10,198.1	0.84
	Sedimentation[a]	32,634.7	0.70	8,157.8	0.70	40,792.5	0.70
	Representative Primary Device Total Annual Cost = $4,000 per mgd ($1.05/m^3/day)						
Secondary	Contact Stabilization[g]	19,585.7	0.85	4,894.7	0.85	24,480.4	0.85
	Physical-Chemical[e]	32,634.7	0.85	8,157.8	0.85	40,792.5	0.85
	Representative Secondary Device Total Annual Cost = $15,000 per mgd ($3.93/m^3/day)						
Storage	High Density (15 per/ac)	---	---	---	---	51,000.0	1.00
	Low Density (5 per/ac)	---	---	---	---	10,200.0	1.00
	Parking Lot[h]	---	---	---	---	10,200.0	1.00
	Rooftop[h]	---	---	---	---	5,100.0	1.00
	Representative Annual Storage Cost[j] ($ per ac-in) = $122 $e^{0.16(PD)}$						

T^k = Wet-Weather Treatment Rate in mgd; S^ℓ = Storage Volume in mil gal

[a] ENR = 2200. Includes land costs, chlorination, sludge handling, engineering and contingencies.
[b] Sludge handling costs based on data from Battelle Northwest, 1974.[13]
[c] Field, 1976.[7]
[d] Benjes et al., 1975.[12]
[e] Lager and Smith, 1974.[5]
[f] Maher, 1974.[9]
[g] Agnew et al., 1975.[10]
[h] Wiswall and Robbins, 1975.[11]
[i] For T ≤ 100 mgd. No economies of scale beyond 100 mgd (378,500 m^3/day).
[j] PD = gross population density, persons/acre.
[k] One mgd = 3,785 m^3/day.
[ℓ] One mil gal = 3,785 m^3.

Unfortunately, data on the number and flow rate of stormwater discharges in urban areas could not be found. Thus, it is not possible to determine the optimal mix of treatment plants and pipelines. Therefore, the representative treatment costs shown in Table VI-3 were based on using relatively small plant sizes.

Cost data on detention basins built in the Chicago area for temporary storage of runoff are listed in Table VI-4, Capital Cost of Storage Facilities. Costs of storage tanks built for the purpose of wet-weather quantity and quality control as well as for dry-weather quantity control are also included in this table. Due to the wide variations in these figures, an attempt was made to verify these costs using excavation costs as the basis. Storage costs based on unit excavation costs are listed in Table VI-4. The unit cost of equalization and the estimated costs of rooftop and parking lot storage basins for sewage treatment plants are also shown in Table VI-4. Lastly, analysis of recent estimates of storage costs developed by Benjes *et al*. indicates the following unamortized capital cost C ($ x 10^6) as a function of storage volume, S (mil gal):[12]

Type	Equation	Unit Cost @ S = 10 mil gal $/gal ($/liter)
Earthen	$C = 0.025\ S^{0.73}$	$0.013 ($0.0034)
Concrete w/o Cover	$C = 0.350\ S^{0.58}$	$0.133 ($0.0350)
Concrete w/ Cover	$C = 0.400\ S^{0.79}$	$0.250 ($0.0660)

The data indicate wide variation in the costs of storage. Thus, the relatively simple relationship shown in Table VI-3 was used. Annual storage costs are estimated as a function of gross population density. The curve was derived using an unamortized capital cost of $0.10 per gallon ($0.026/liter) for PD = 5 persons per acre (12.4/ha) and $0.50 per gallon ($0.132/liter) for PD = 15 persons per acre (37.1/ha).

RELATIONSHIP BETWEEN STORAGE/TREATMENT AND PERCENT POLLUTION CONTROL

Use of STORM

STORM was used to evaluate various storage/treatment options for controlling stormwater runoff pollution. This model assumes that the study area can be characterized as a single catchment from which hourly runoff is directed to storage and treatment.

STORM uses a simplified rainfall/runoff relationship, neglects the transport of water through the city and assumes a very simple relationship between storage and treatment. However, these simplifications are essential if one hopes to do a continuous simulation. The continuous simulation approach was used because no general concurrence exists

Table VI-4. CAPITAL COST OF STORAGE FACILITIES[a]

	Capacity mil gal (1000 m^3)	Capital Cost $/gal ($/liter)	
Storage Reservoirs[b]			
Hillside Park	11.4 (43.1)	0.01 (0.003)	Earthen Basin
Heritage Park	36.5 (138.0)	0.01 (0.003)	Earthen Basin
Oak Lawn	7.8 (29.5)	0.02 (0.005)	Earthen Basin
Middle Fork North Branch	195.5 (740.0)	0.02 (0.005)	Earthen Basin
Wilke-Kirchoff	32.6 (123.0)	0.03 (0.008)	Earthen Basin
Melvina Dutch	53.8 (204.0)	0.03 (0.008)	Earthen Basin
Oak Hill Park	25.1 (95.0)	0.02 (0.005)	Earthen Basin
Dolphin Park	53.8 (204.0)	0.01 (0.003)	Earthen Basin
Average	52.1 (197.0)	0.019 (0.005)	
Storage Tanks[e]			
Cottage Farm, Boston[c]	1.3 (4.9)	5.21[d] (1.38)	Covered Conc. Tanks
Spring Creek, New York[c]	10.0 (37.8)	2.33 (0.62)	Covered Conc. Tanks
Chippewa Falls, Wisconsin[c]	2.8 (10.6)	0.29 (0.08)	Asphalt Paved Basin
Humboldt Avenue, Milwaukee[c]	4.0 (15.1)	0.55 (0.14)	Covered Conc. Tanks
Seattle, Washington	32.0 (121.0)	0.25 (0.07)	In-line
Whittier Narrow, Columbus[c]	4.0 (15.1)	1.70 (0.45)	Open Concrete Tanks
Average	9.0 (34.1)	1.72 (0.45)	
Based on Excavation Costs[f]			
$2/cu yd ($2.62/cu m)		0.01 (0.003)	Earthen Basin
$5/cu yd ($6.54/cu m)		0.025 (0.007)	Earthen Basin in Rock
Equalization Basins for Dry Weather Sewage Treatment Plants[g]	1.0 (3.8)	0.22 (0.06)	Earthen Basin
	3.0 (11.4)	0.10 (0.03)	Earthen Basin
	10.0 (37.8)	0.06 (0.02)	Earthen Basin
	1.0 (3.8)	0.39 (0.10)	Concrete Basin
	3.0 (11.4)	0.28 (0.07)	Concrete Basin
	10.0 (37.8)	0.25 (0.07)	Concrete Basin
Other[h]			
Parking Lots		0.10 (0.03)	
Rooftops		0.05 (0.02)	

[a] Based on ENR = 2200.

[b] Source: Metropolitan Sanitary District of Greater Chicago.

[c] Also used for stormwater treatment.

[d] Includes pumping station, chlorination and outfall facilities.

[e] Source: Lager and Smith, 1974.[5]

[f] Soil Conservation Service, Gainesville, FL

[g] Source: Anon., "Flow Equalization-Plus for Wastewater Treatment Plants," Civil Engineering, Vol. 45, No. 9, September 1975, pp. 66-68.[21]

[h] Source: Wiswall and Robbins, 1975.[13]

regarding an appropriate single event that one should analyze. The degree of control can be expressed in terms of the percent of the runoff treated, the annual number of overflows, or the amount of pollutants discharged to the receiving waters.

As described in the User's Manual, STORM computes the runoff based on the composite runoff coefficient and the effective precipitation.[14] The depression storage must be satisifed before the runoff coefficient is applied to the precipitation. The amount of depression storage available in ditches, depressions, and other surfaces is a function of the past precipitation and the evaporation rates. Each hour that runoff occurs, the model compares it to the treatment rate. As long as the runoff rate is less than or equal to the treatment rate all the runoff passes directly through the treatment plant and storage is not utilized. When the runoff rate exceeds the treatment rate, the excess runoff is sent to storage. If excess runoff occurs frequently enough to exceed the storage capacity then overflow occurs. When runoff falls below the treatment rate then storage is depleted at the excess treatment rate. The hourly occurrence of treated runoff, stored runoff, and runoff that has overflowed is tabulated for the entire record of rainfall. Included in the output is the annual number of overflow events and the percentage of the runoff that overflowed to the receiving waters. This type of analysis was carried out for different storage capacities and treatment rates.

STORM Input Data For Detailed Study of Five Test Cities

STORM requires several input parameters that characterize the urban area under study. These include hourly precipitation, total area, land use types and percentages, percent imperviousness and curb length per area for each land use. Local data used to run STORM on the five study areas were collected by onsite interviews. The main source used by APWA to characterize the urbanized areas was information developed by the National Planning Data Corporation (NPDC) (see Section III). The percent imperviousness and length of street gutters were found by their relationship to population density using Stankowski's equation for imperviousness and APWA's equation for curb length density (Volume III) described in the two previous sections.[15] Daily evaporation rates for each month are from a report by Thornthwaite and Mather.[16] The depression storage is assumed to be 0.01 inches (0.025 cm) for all cities. A summary of input data for all of the study areas is given in Table VI-5, STORM Input Data for Study Areas. The hydrologic data for the study areas are shown in Table VI-6, Hydrologic Data for Study Areas.

Hourly precipitation data were acquired from the US Environmental Data Service in Asheville, North Carolina. Twenty-five years (January 1948 to December 1972) of hourly data were obtained for the five test cities. Two and one-half years (July 1970 to December 1972) of data were obtained for all stations in the United States.

Table VI-5. STORM INPUT DATA FOR STUDY AREAS

Study Area: Atlanta
Area: 278,400 ac (112,800 ha)
Depression Storage: 0.01 in. (0.025 cm)

Daily evaporation rates for each month, Jan-Dec, in in/day (cm/day)

0.01	0.02	0.04	0.07	0.10	0.11	0.10	0.08	0.06	0.04	0.02	0.01
(0.03)	(0.05)	(0.10)	(0.18)	(0.25)	(0.28)	(0.25)	(0.20)	(0.15)	(0.10)	(0.05)	(0.03)

Study Area: Denver
Area: 187,500 ac (75,900 ha)
Depression Storage: 0.01 in. (0.025 cm)

Daily evaporation rates for each month, Jan-Dec, in in/day (cm/day)

0.0	0.0	0.01	0.02	0.04	0.07	0.09	0.08	0.06	0.05	0.03	0.01
(0.0)	(0.0)	(0.03)	(0.05)	(0.10)	(0.18)	(0.23)	(0.20)	(0.15)	(0.13)	(0.08)	(0.03)

Study Area: Minneapolis
Area: 461,400 ac (186,700 ha)
Depression Storage: 0.01 in. (0.025 cm)

Daily evaporation rates for each month, Jan-Dec, in in/day (cm/day)

0.0	0.0	0.0	0.02	0.04	0.06	0.07	0.06	0.05	0.04	0.02	0.0
(0.0)	(0.0)	(0.0)	(0.05)	(0.10)	(0.15)	(0.18)	(0.15)	(0.13)	(0.10)	(0.05)	(0.0)

Study Area: San Francisco
Area: 435,800 ac (176,400 ha)
Depression Storage: 0.01 in. (0.025 cm)

Daily evaporation rates for each month, Jan-Dec, in in/day (cm/day)

0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01
(0.03)	(0.03)	(0.03)	(0.05)	(0.03)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.03)

Study Area: Washington, DC
Area: 316,800 ac (128,200 ha)
Depression Storage: 0.01 in. (0.025 cm)

Daily evaporation rates for each month, Jan-Dec, in in/day (cm/day)

0.0	0.0	0.01	0.02	0.03	0.05	0.05	0.05	0.03	0.02	0.01	0.0
(0.0)	(0.0)	(0.03)	(0.05)	(0.08)	(0.13)	(0.13)	(0.13)	(0.08)	(0.05)	(0.03)	(0.0)

Table VI-6. HYDROLOGIC DATA FOR STUDY AREAS

Study Area	Year	Rainfall in. (cm)	Imperviousness, I/100	Runoff[a] Coefficient, CR	Annual Runoff[b] AR, in. (cm)
Atlanta	1969	44.40 (113.0)	0.299	0.374	16.18 (41.10)
Denver	1960	14.98 (38.0)	0.314	0.386	5.59 (14.20)
Minneapolis	1971	29.29 (74.4)	0.293	0.370	10.50 (26.70)
San Francisco	1967	24.26 (61.6)	0.329	0.397	9.37 (23.80)
Washington, DC	1969	43.30 (110.0)	0.339	0.404	17.22 (43.70)

[a] $CR = 0.15(100-I)/100 + 0.90\ I/100$

[b] From STORM analysis.

The frequency distribution of each of the twenty-five years of rainfall was analyzed for each of the five cities. Little year-to-year variation in the distributions was noted, but there was considerable variation among cities. The annual frequency for twenty-five years of rainfall is shown for the cities in Figure VI-3, Average Twenty-Five Year Rainfall Duration for Each Study Area.

In the early stages of the research it became apparent that multiple runs of STORM would be required on each city to adequately determine the effectiveness of different storage capacities and treatment rates. It was also discovered that making STORM runs using the entire twenty-five years of rainfall for each city was expensive and time consuming.

Since the useful information was in terms of the overall level of control of the runoff, it appeared adequate to run STORM on a single year if the results were the same as running STORM for the entire twenty-five year period. The frequency distributions for the single year chosen for each city are shown in Figure VI-4, Selected One-Year Rainfall Duration for Each Study Area. These may be compared to Figure VI-3 to see how the typical year compares to the twenty-five year average. The monthly distribution for the study year is shown for each study area in Figure VI-5, Monthly Rainfall Distribution for Study Year for Each Study Area. The comparisons indicated that running a single year would be adequate for our purposes.

STORM RESULTS

For each storage/treatment rate combination, there is a value for the percent of the runoff and pollutants which are "treated." By making several runs at different combinations of treatment and storage, points were generated representing different levels of control. Then isoquants were drawn connecting the points that represent combinations of storage capacities and treatment rates which give equivalent percent runoff and/or pollutant "treated." If the concentration of pollutants is constant and "treatment" efficiency, η, is 1.0, then percent runoff control is synonymous with percent pollutant control. Obviously, this is not the case. Thus, account needs to be taken of

1. treatment efficiency, and
2. variable concentration due to first flush effects.

Adjustment for Treatment Efficiency

Let R denote the percent runoff control and η equal treatment plant efficiency. If R_1 denotes the percent pollutant control, then to realize R_1, one needs to process R_1/η of the runoff. Note that R_1 may be percent BOD removal, percent SS removal, etc. In Table VI-1, representative

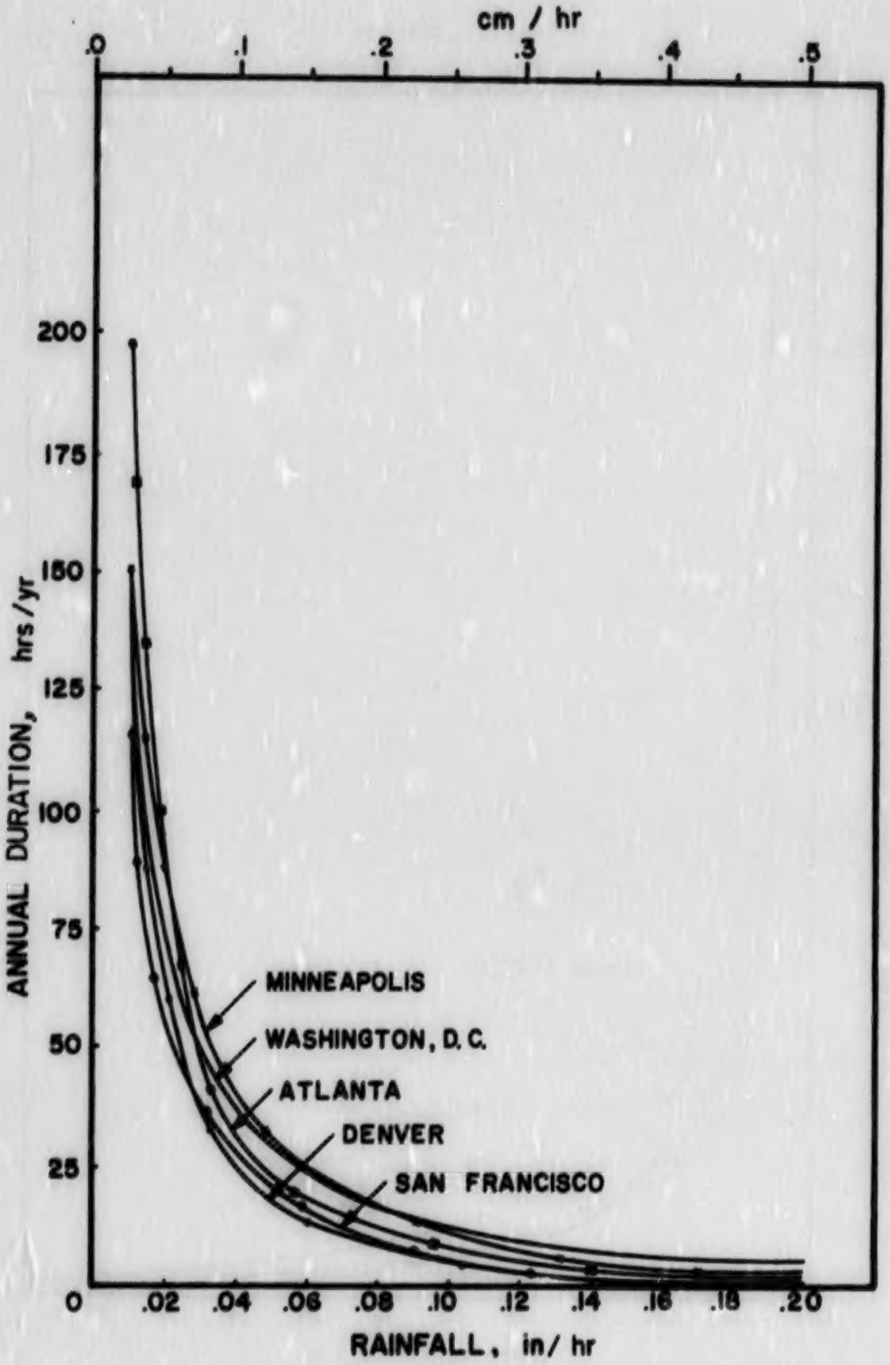

Figure VI-3. Average Twenty-Five Year Rainfall Duration for Each Study Area

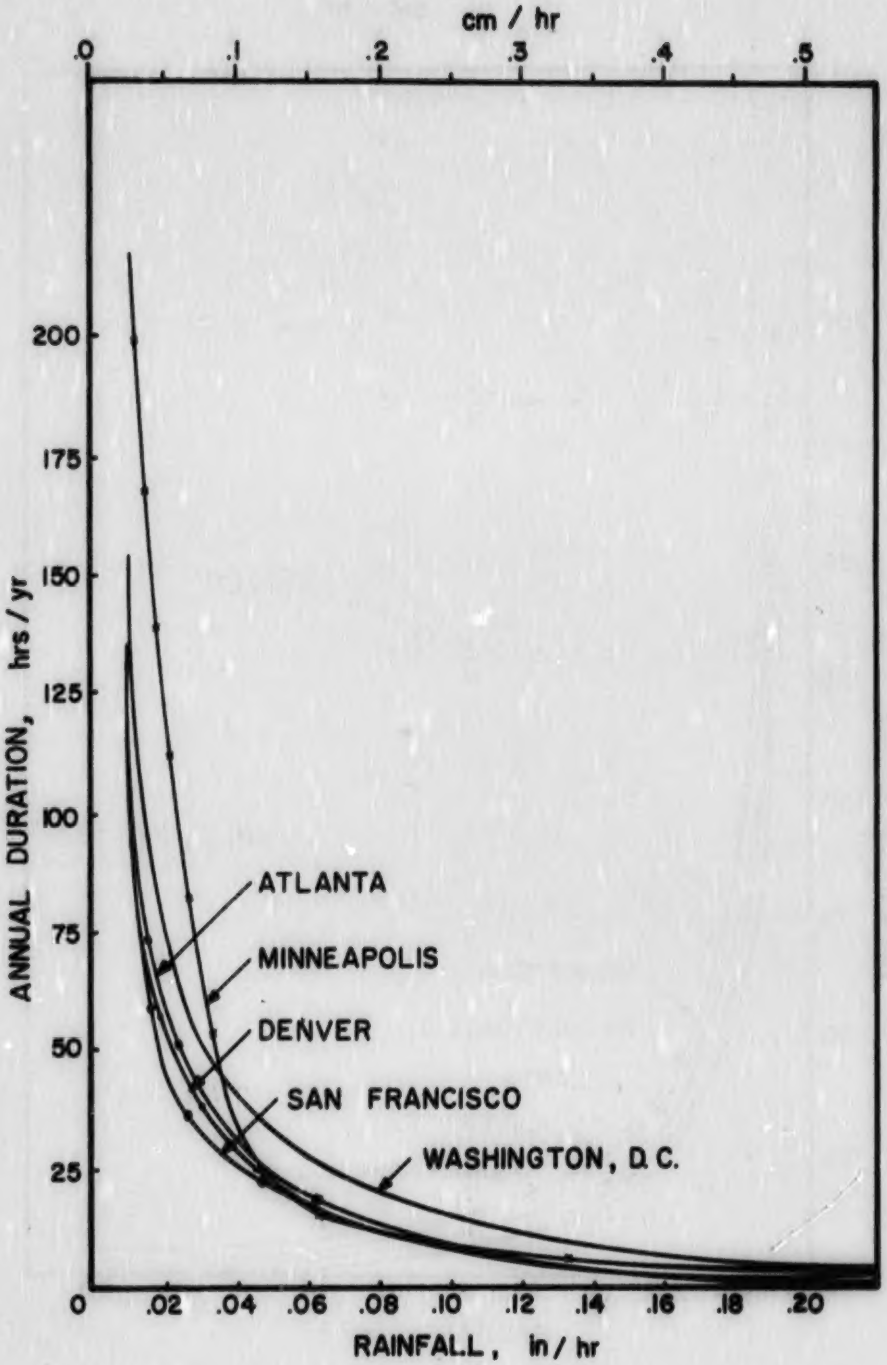

Figure VI-4. Selected One-Year Rainfall Duration for Each Study Area

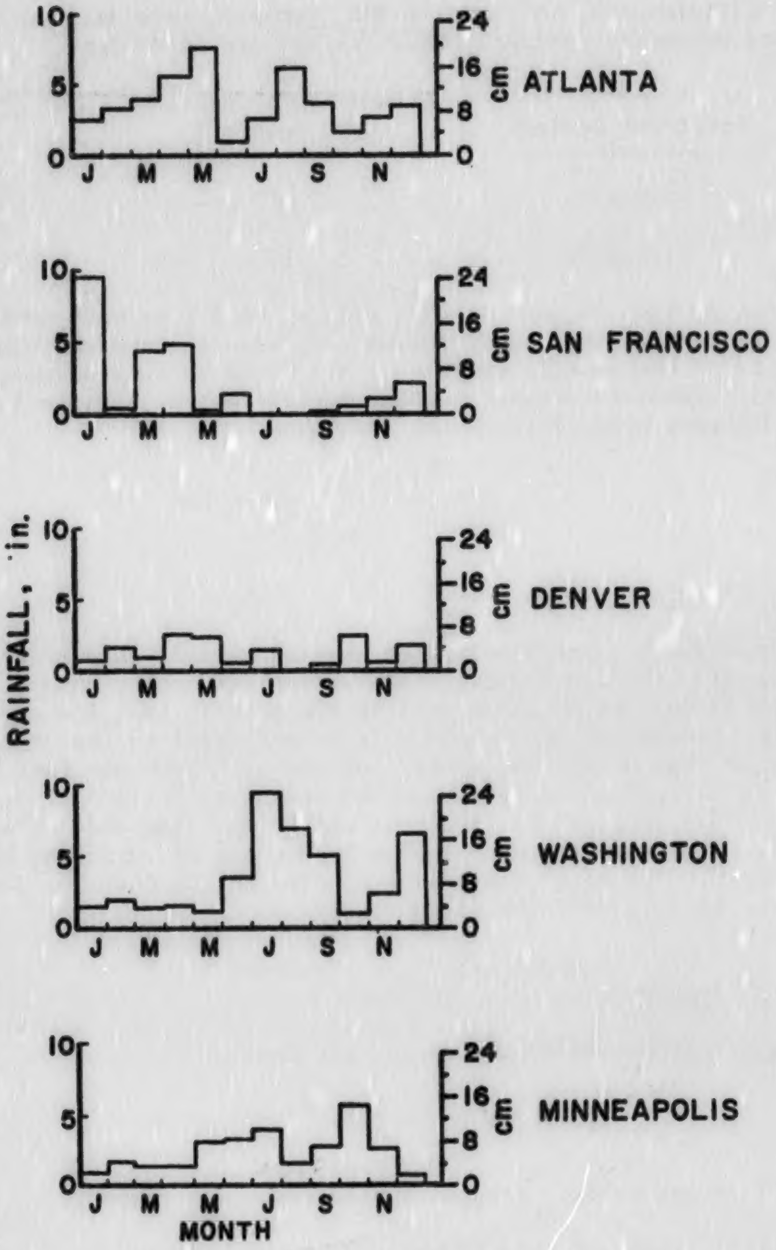

Figure VI-5. Monthly Rainfall Distribution for Study Year for Each Study Area

treatment efficiencies, in terms of BOD_5 removal, were derived for primary and secondary devices. These values are as follows:

Treatment Device	Assumed Efficiency, η (BOD_5 Removal)
Primary	0.40
Secondary	0.85

Thus, if one desires 25 percent BOD_5 removal with a primary device, then 62.5 percent of the runoff volume must be processed whereas only 29.4 percent of the runoff needs to be processed if a secondary device is selected. Thus, to convert percent runoff control isoquants to percent pollutant control isoquants, one uses

$$R = \frac{R_1}{\eta} . \qquad 0 \leq R \leq 100 \qquad \text{(VI-3)}$$

Adjustment for First Flush

STORM estimates the percent pollutant control as well as percent runoff control. The STORM model runs incorporated the standard first flush assumption which is used in the model, i.e., the amount of pollutant removal at any time, t, is proportional to the amount remaining and that a uniform runoff of one-half inch per hour would wash away 90 percent of the pollutant in one hour.[14] If a first flush is assumed, then storage and treatment can be operated more effectively because of the greater relative importance of capturing the initial runoff. The first flush is accounted for by defining the output in terms of pollutant control directly.

Mathematical Representation of Isoquants

The storage/treatment isoquants are of the form:

$$T = T_1 + (T_2 - T_1)e^{-KS} \qquad \text{(VI-4)}$$

where T = wet-weather treatment rate, inches per hour,

T_1 = treatment rate at which isoquant becomes asymptotic to the ordinate, inches per hour,

T_2 = treatment rate at which isoquant intersects the abscissa, inches per hour,

S = storage volume, inches, and

K = constant, inch^{-1}.

A relatively large storage reservoir is required to operate the treatment unit continuously. Thus, first flush affects would be dampened out and the effluent concentration from the reservoir should be relatively uniform. Thus, if stormwater entering the treatment plant has a relatively uniform concentration, then T_1 can be found as follows (using 8,760 hours per year):

$$T_1 = \frac{AR}{8760}\left(\frac{R}{100}\right) = aR \qquad \text{(VI-5)}$$

where AR = annual runoff, inches per year, and

R = percent runoff control.

By relating the parameters T_1, T_2-T_1 and K to the level of control R, one equation was developed for each of the five cities. The T_2-T_1 and K terms versus R were found to be of the following general form:

$$T_2 - T_1 = be^{hR} \qquad \text{(VI-6)}$$

$$K = de^{-fR} \qquad \text{(VI-7)}$$

Based on this analysis the following general equation for the isoquants is obtained:

$$T = aR + be^{hR-(de^{-fR})S}. \qquad \text{(VI-8)}$$

The values of parameters a, b, h, d and f for various cities are presented in Table VI-7, Values of Parameters and Correlation Coefficients for Isoquant Equations for Percent BOD Control Without First Flush and Table VI-8, Values of Parameters and Correlation Coefficients for Isoquant Equations for Percent BOD Control With First Flush. The correlation coefficients for the equations for the four cities are also shown in these tables. In general, the fits are excellent.

The results for the five cities are shown in Figures VI-6, Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region I - San Francisco, VI-7, Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region II - Denver, VI-8, Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region III - Minneapolis, VI-9, Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region IV - Atlanta, and VI-10, Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region V - Washington, DC. Each figure shows the isoquants calculated by the isoquant equation. Also shown are some actual data points for a treatment rate of 0.01 inches per hour and varying amounts of storage.

Table VI-7. VALUES OF PARAMETERS AND CORRELATION COEFFICIENTS FOR ISOQUANT EQUATIONS FOR PERCENT BOD CONTROL WITHOUT FIRST FLUSH

Note: Values are for developed portion of test cities and for $\eta = 1.0$.

Test City	a in. $hr^{-1}(\% R)^{-1}$ (cm hr^{-1})	b in. hr^{-1} (cm hr^{-1})	h $(\% R)^{-1}$	d $in.^{-1}$ (cm^{-1})	f $(\% R)^{-1}$	Correlation $T_2-T_1=be^{cR}$	Coefficient $K=de^{-fR}$
San Francisco	0.0000107 (0.0000272)	0.0021466 (0.0054524)	0.0377090	108.5330 (275.6738)	0.0335173	0.9821	-0.9888
Denver	0.0000064 (0.0000163)	0.0012194 (0.0030973)	0.0397305	119.8106 (304.3189)	0.0279204	0.9931	-0.9791
Minneapolis	0.0000120 (0.0000305)	0.0012909 (0.0032789)	0.0487845	191.2782 (485.8466)	0.0322136	0.9963	-0.9913
Atlanta	0.0000185 (0.0000470)	0.0022832 (0.0057993)	0.0486532	112.2002 (284.9885)	0.0348027	0.9905	-0.9712
Washington, DC	0.0000197 (0.0000500)	0.0020464 (0.0051979)	0.0567454	117.5456 (298.5650)	0.0398007	0.9925	-0.9759

Table VI-8. VALUES OF PARAMETERS AND CORRELATION COEFFICIENTS FOR ISOQUANT EQUATIONS FOR PERCENT BOD CONTROL WITH FIRST FLUSH

Note: Values are for developed portion of test cities and for $\eta = 1.0$.

Test City	a in. $hr^{-1}(\% R)^{-1}$ (cm hr^{-1})	b in. hr^{-1} (cm hr^{-1})	h $(\% R)^{-1}$	d $in.^{-1}$ (cm^{-1})	f $(\% R)^{-1}$	Correlation $T_2-T_1=be^{R}$	Coefficient $K=de^{-fR}$
San Francisco	0.0000107 (0.0000271)	0.0021654 (0.0055001)	0.0388910	211.2763 (536.6418)	0.0320226	0.9893	-0.9898
Denver	0.0000064 (0.0000162)	0.0013631 (0.0034622)	0.0439822	184.9639 (469.8083)	0.0279177	0.9903	-0.9926
Minneapolis	0.0000120 (0.0000304)	0.0013656 (0.0034686)	0.0481981	241.6141 (613.6998)	0.0301648	0.9956	-0.9958
Atlanta	0.0000185 (0.0000469)	0.0025864 (0.0065694)	0.0468175	190.2240 (483.1690)	0.0312484	0.9857	-0.9899
Washington,DC	0.0000197 (0.0000500)	0.0018959 (0.0048155)	0.0487876	228.8434 (581.2622)	0.0339322	0.9933	-0.9896

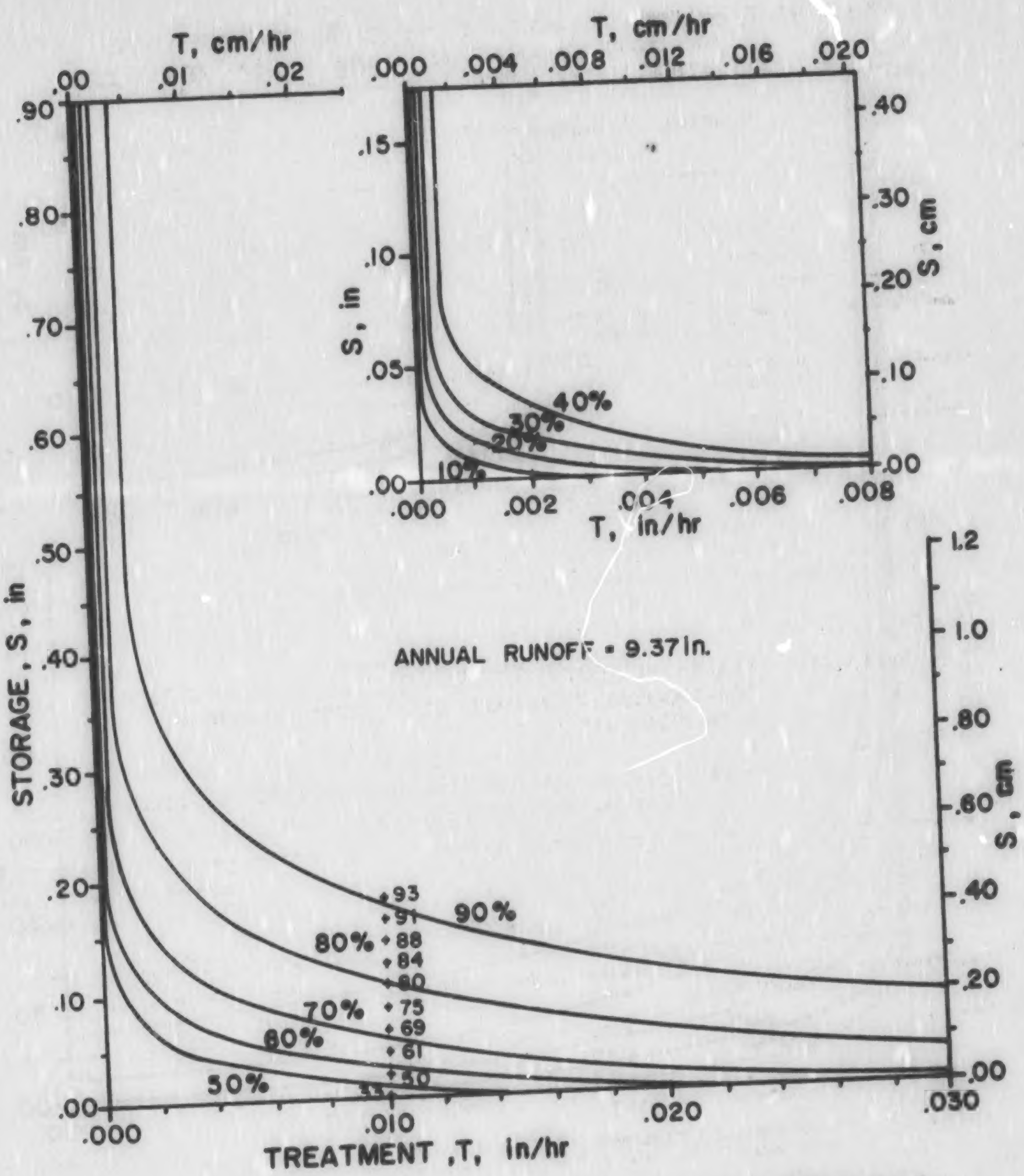

Figure VI-6. Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region I - San Francisco

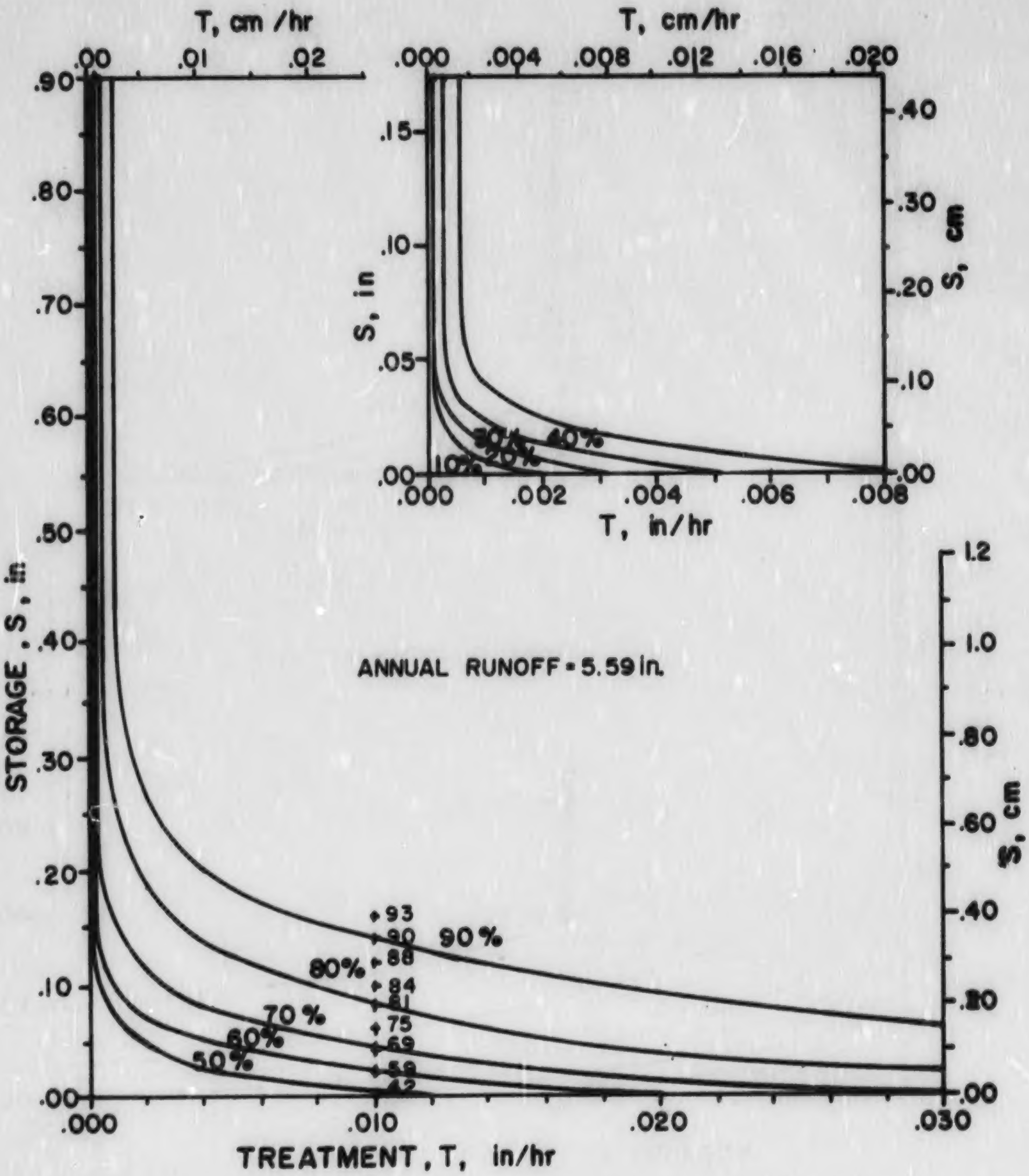

Figure VI-7. Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region II - Denver

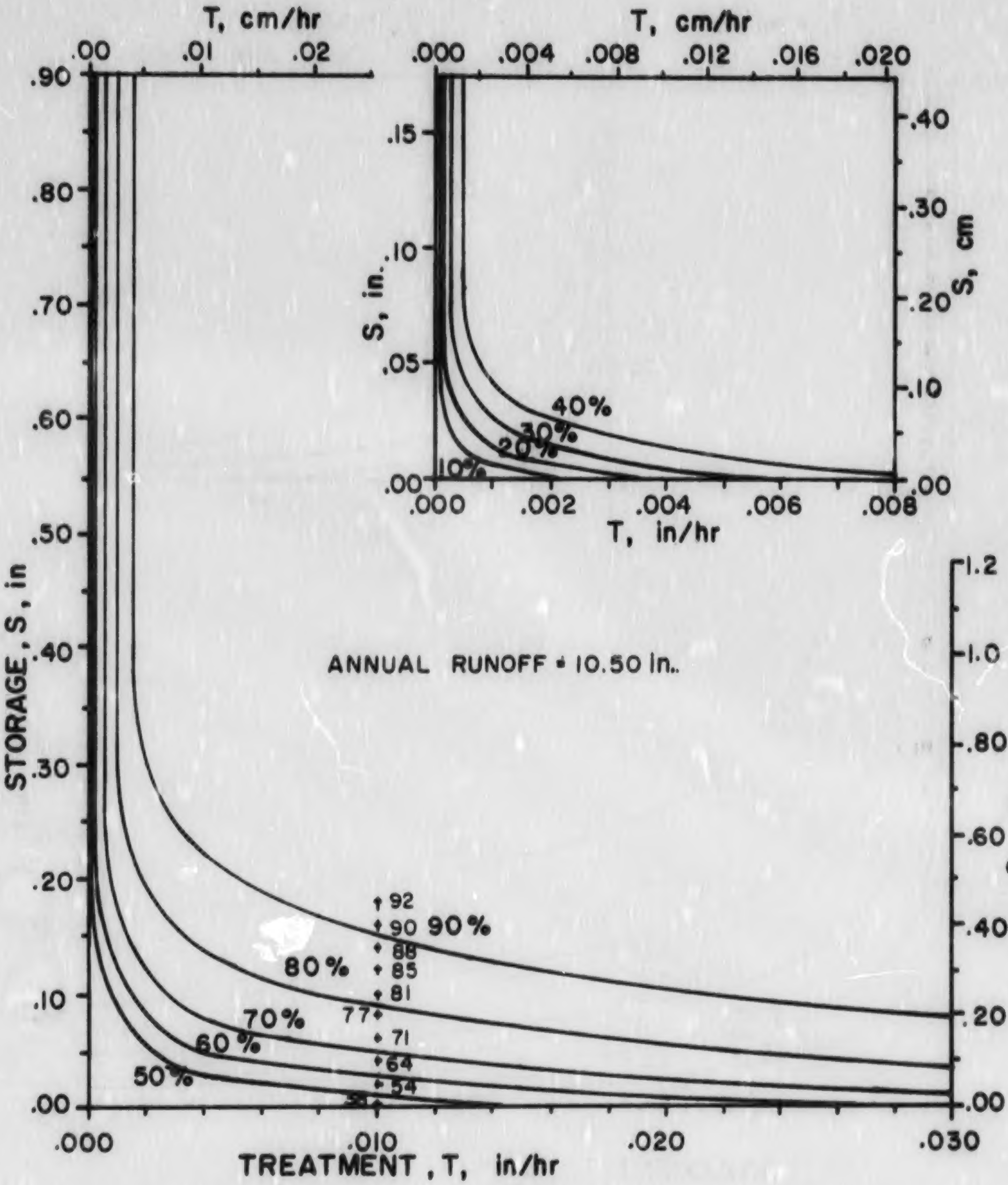

Figure VI-8. Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region III - Minneapolis

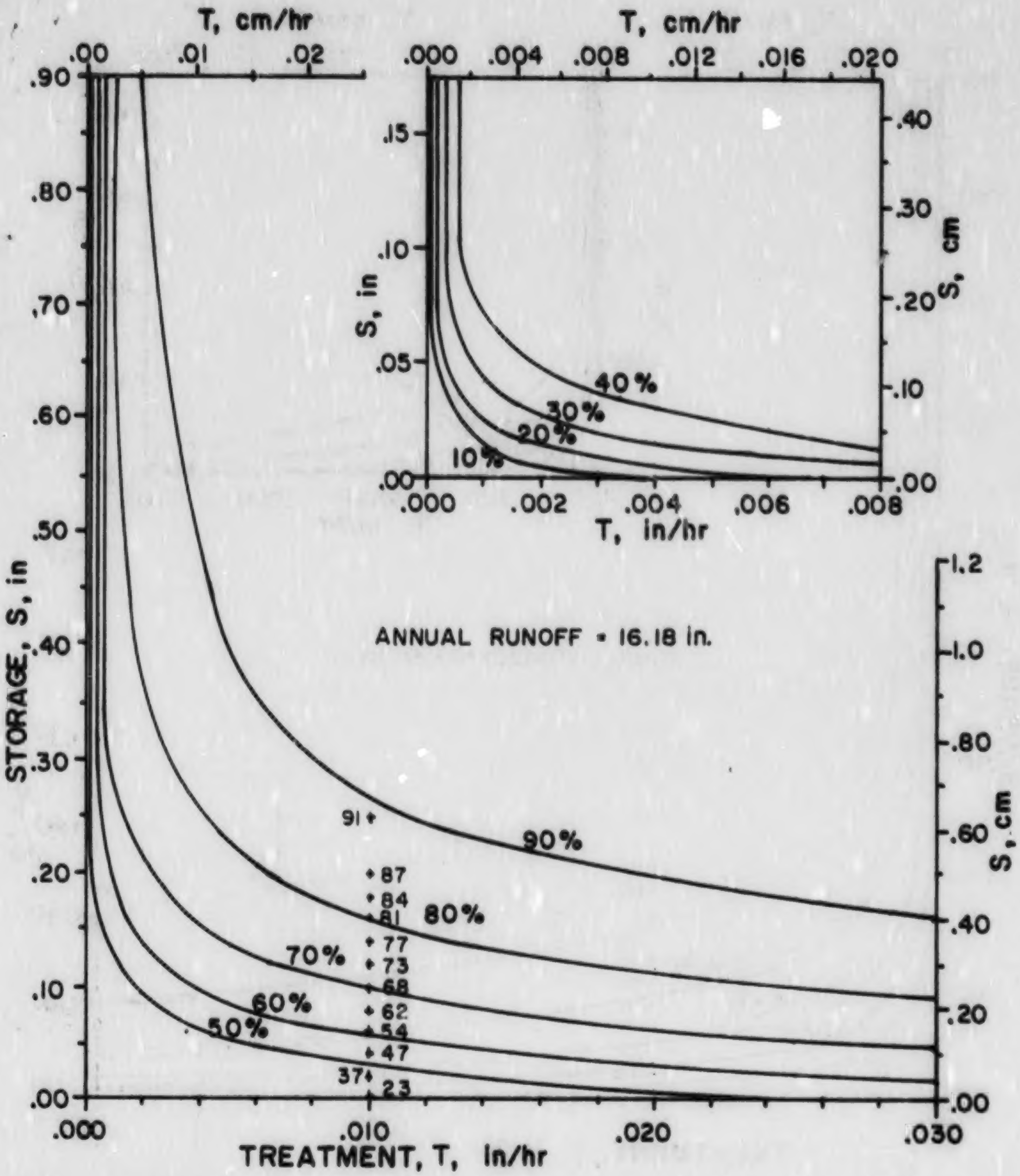

Figure VI-9. Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region IV - Atlanta

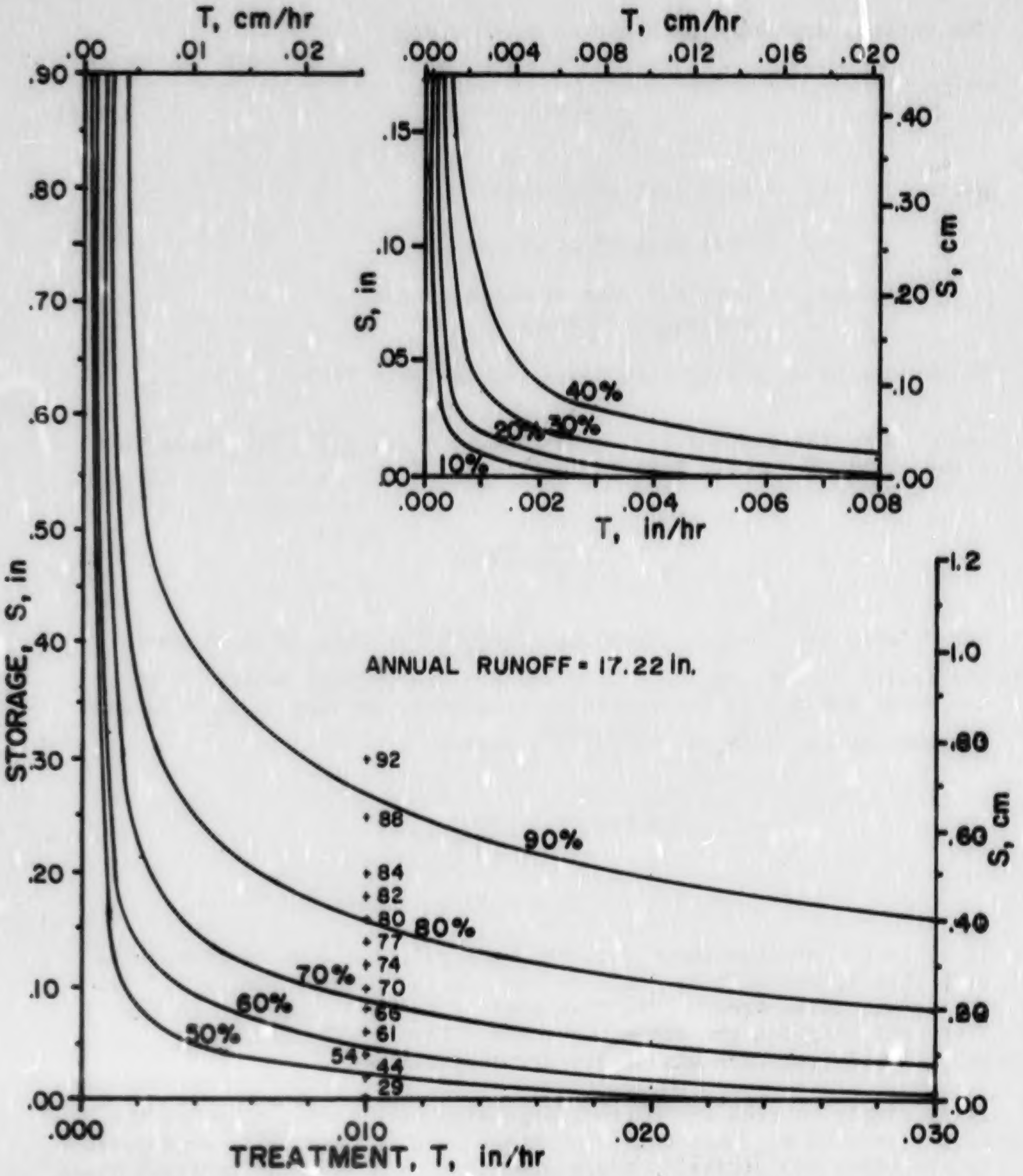

Figure VI-10. Storage-Treatment Isoquants for Percent BOD Removal with First Flush - Region V - Washington, DC

The optimal expansion path can be found using

$$\frac{c_T}{c_S} = \mathrm{MRS}_{ST} \qquad \text{(VI-9)}$$

where c_S = unit cost of storage,

c_T = unit cost of treatment, and

MRS_{ST} = marginal rate of substitution of storage for treatment.

The values of c_S and c_T were presented in Table VI-3.

Analysis of the figures indicates that if $c_T/c_S \leq 25$, then treatment alone should be used. From Table VI-3,

$$\frac{c_T}{c_S} = \frac{c_T}{122\ e^{0.16(PD)}} .$$

For primary treatment, $c_T = \$2{,}610/\frac{\text{acre-inch}}{\text{hour}}$. Thus, even at zero population density, $c_T/c_S = 21.4$ so that the optimal policy is to use treatment only. For secondary treatment, letting $c_T/c_S = 25$ and knowing that $c_T = \$9{,}800/\frac{\text{acre-inch}}{\text{hour}}$, yields

$$122\ e^{0.16(PD)} = \frac{9800}{25}, \text{ or}$$

$$PD = 7.29 \text{ persons/acre.}$$

If PD is higher than about 7.5, then the relative cost of storage is such that it is again optimal to use treatment only. Using 7.5 persons per acre as the cutoff, then some of the 248 cities would use treatment only for the secondary control level. The remaining cities would select a mix of storage and treatment.

It is simple to find the optimal expansion path graphically for the five test cities. Unfortunately, these results need to be extrapolated to the other 243 cities. It appeared that an analytical approach would provide a more general and consistent procedure. Thus, the isoquant parameters were adjusted based on the runoff in the city under consideration relative to the reference city, i.e., let AR_i = annual runoff in city i; i = 1,2,...,248

AR_j = annual runoff in test city for region j; j = 1, 2, 3, 4, 5.

Then, the isoquant coefficients are

$$a_{ij} = \frac{AR_i}{(8.76 \times 10^5)} \tag{VI-10}$$

$$b_{ij} = \frac{AR_i}{AR_j} b_j, \tag{VI-11}$$

$$h_{ij} = h_j, \tag{VI-12}$$

$$d_{ij} = \frac{AR_j}{AR_i} d_j, \text{ and} \tag{VI-13}$$

$$f_{ij} = f_j, \tag{VI-14}$$

where a_{ij}, b_{ij}, h_{ij}, d_{ij}, and f_{ij} are parameters for city i in region j and b_j, h_j, d_j, and f_j are the parameters for the test city in region j. The test cities are denoted as follows:

j =	City
1	San Francisco
2	Denver
3	Minneapolis
4	Atlanta
5	Washington, DC.

Wet-Weather Quality Control Optimization

The wet-weather optimization problem, assuming linear costs, may be stated as follows:

minimize

$$Z = c_S S + c_T T \tag{VI-15}$$

subject to

$$T = T_1 + (T_2 - T_1)e^{-KS}$$

$$T,S \geq 0.$$

Solving this constrained optimization problem yields

$$S^* = \max \left[\frac{1}{K} \ln \frac{c_T}{c_S} [K(T_2 - T_1)], 0\right] \qquad \text{(VI-16)}$$

where S* = optimal amount of storage, inches,

and

$$T^* = T_1 + (T_2 - T_1)e^{-KS^*} \qquad \text{(VI-17)}$$

where T* = optimal amount of treatment, inches per hour.

Note that T* is expressed as a function of S*, so it is necessary to find S* first. Knowing S* and T*, the optimal solution is

$$Z^* = c_S S^* + c_T T^* \qquad \text{(VI-18)}$$

where Z* = total annual cost for optimal solution, dollars per acre.

Data needed to estimate T_1, T_2 and K have already been presented in the previous subsection.

For a primary device, $c_T = \$4,000/\text{mgd} = \$2,610/\frac{\text{acre-inch}}{\text{hour}} = \$1.05/\frac{m^3}{\text{day}}$.

For storage cost,

$$c_S(\$/\text{acre-inch}) = 122\ e^{0.16(PD)} \qquad \text{(VI-19)}$$

where PD = gross population density in persons per acre.

The above optimization procedure was programmed to generate curves, e.g., Figure VI-11, Control Costs for Primary and Secondary Units in Storm Sewered Areas, Atlanta, showing percent pollutant removed versus total annual costs for primary and secondary treatment in conjunction with storage. Note that, for wet-weather control, marginal costs are increasing because of the disproportionately larger sized control units needed to capture the less frequent larger runoff volumes.

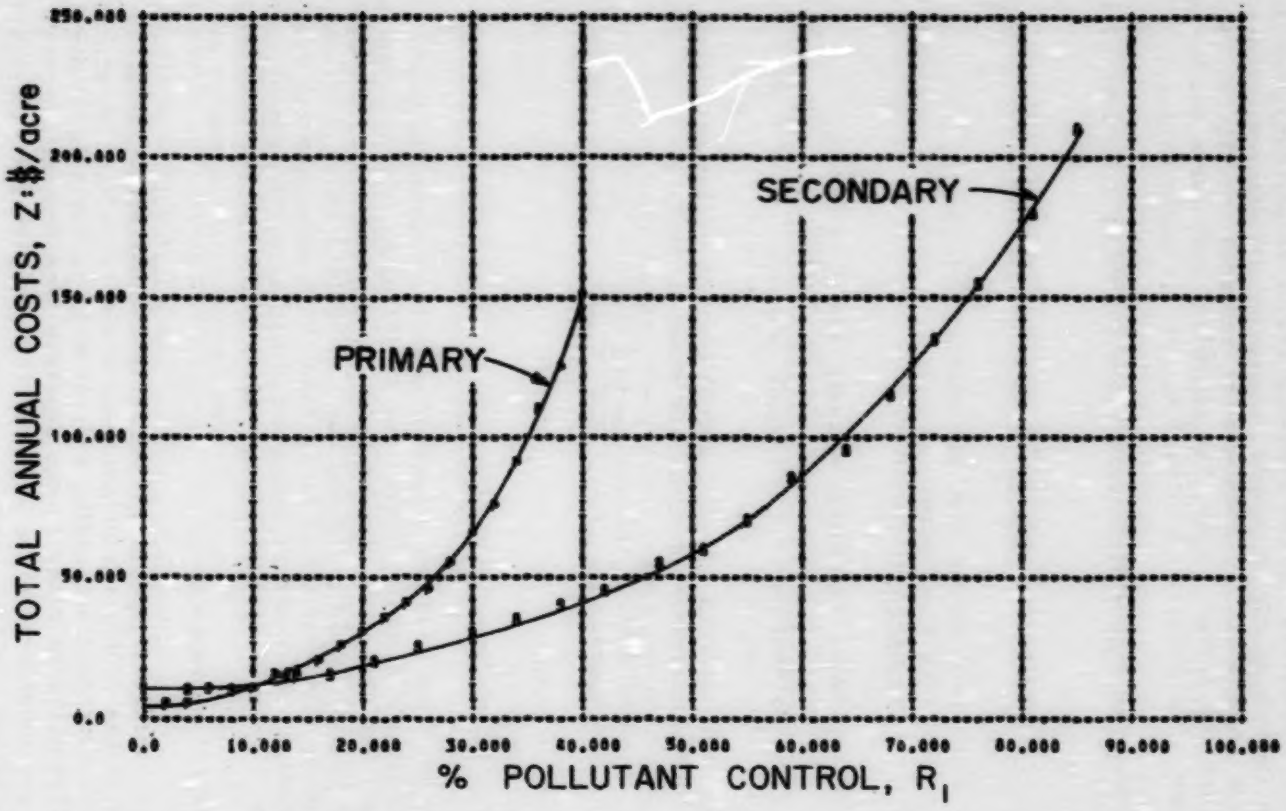

Figure VI-11. Control Costs for Primary and Secondary Units in Storm Sewered Areas, Atlanta

These results also permit one to decide whether a primary or a secondary control level is more cost-effective in controlling smaller percentages of pollution. As seen in Figure VI-11, a primary control device is less expensive for low removals (say ≤ 20 percent), but it loses effectiveness at higher levels because of the disproportionately large storage requirements. Costs will be reported for 25, 50, 75, and 85 percent control levels. Thus, the secondary cost curve can be used in this range. The primary curve will not be discussed further.

The curves shown in Figure VI-11 were approximated by functions of the form:

$$Z^* = ke^{\beta R_1} \tag{VI-20}$$

where Z^* = total annual cost for optimal solution, dollars per acre,

k, β = parameters,

R_1 = percent pollutant removal, $0 \leq R_1 \leq \bar{R}_1$, and

$\bar{R}_1$ = maximum percent pollutant removal.

The resulting costs for 25, 50, 75, and 85 percent pollutant control for combined, storm, and unsewered areas are shown in Table VI-9, Annual Control Costs - Combined Areas, Table VI-10, Annual Control Costs - Storm Areas, and Table VI-11, Annual Control Costs - Unsewered Areas. The reference city and values of the cost equation parameters are also shown.

Estimating Number of Overflow Events

Some urban areas have used the number of overflow events per year as an indication of level of control due to different storage/treatment combinations. San Francisco, for example, is concerned with the number of times the beaches would be closed due to combined sewer overflows. The objective in this case would be to find the most economical combination of storage and treatment which would not allow the annual number of overflows to exceed a predetermined value. It would not seem logical to increase the treatment rate or storage capacity if the number of overflows did not decrease.

The number of overflow events is affected by the definition of an "event" used in the STORM model wherein an event is defined as starting when storage is utilized and ending when storage is depleted. Even though overflow may take place in two separate time frames, the two occurrences are considered to be parts of the same event if storage is utilized throughout the time frame.

TABLE VI-9 ANNUAL CONTROL COSTS - COMBINED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. B	CONTROL COST ($/ACRE) 25%	50%	75%	85%
1	CT	BRIDGEPORT	5	9.46	0.043	28.	80.	233.	358.
1	CT	BRISTOL	5	0.0	0.0	0.	0.	0.	0.
1	CT	DANBURY	5	0.0	0.0	0.	0.	0.	0.
1	CT	HARTFORD	5	10.65	0.043	31.	92.	270.	416.
1	CT	MERIDEN	5	0.0	0.0	0.	0.	0.	0.
1	CT	NEW BRITAIN	5	0.0	0.0	0.	0.	0.	0.
1	CT	NEW HAVEN	5	9.61	0.043	28.	81.	238.	358.
1	CT	NORWALK	5	33.20	0.057	136.	561.	2308.	4063.
1	CT	STAMFORD	5	0.0	0.0	0.	0.	0.	0.
1	CT	WATERBURY	5	10.48	0.043	31.	89.	259.	397.
1	CT	OTHER URBAN AREAS		10.56	0.046	33.	102.	321.	510.
1	CT	AVE. FOR STATE		10.56	0.046	33.	102.	321.	510.
1	ME	LEWISTON	5	7.42	0.042	21.	60.	171.	259.
1	ME	PORTLAND	5	4.91	0.041	14.	37.	102.	154.
1	ME	OTHER URBAN AREAS		5.69	0.041	16.	44.	124.	187.
1	ME	AVE. FOR STATE		5.69	0.041	16.	44.	124.	187.
1	MA	BOSTON	5	15.23	0.044	46.	139.	422.	657.
1	MA	BROCKTON	5	0.0	0.0	0.	0.	0.	0.
1	MA	FALL RIVER	5	10.61	0.043	31.	91.	264.	406.
1	MA	FITCHBURG	5	10.21	0.043	30.	88.	251.	384.
1	MA	LAWRENCE	5	6.88	0.042	20.	56.	158.	240.
1	MA	LOWELL	5	11.08	0.043	33.	97.	288.	444.
1	MA	NEW BEDFORD	5	7.92	0.042	23.	65.	188.	287.
1	MA	PITTSFIELD	5	0.0	0.0	0.	0.	0.	0.
1	MA	SPRINGFIELD	5	5.32	0.041	15.	41.	112.	168.
1	MA	WORCESTER	5	17.31	0.045	53.	160.	488.	761.
1	MA	OTHER URBAN AREAS		9.20	0.043	27.	79.	231.	356.
1	MA	AVE. FOR STATE		9.20	0.043	27.	79.	231.	356.
1	NH	MANCHESTER	5	6.61	0.042	19.	53.	151.	230.
1	NH	NASHUA	5	4.73	0.040	13.	36.	98.	148.
1	NH	OTHER URBAN AREAS		5.84	0.041	16.	46.	130.	196.
1	NH	AVE. FOR STATE		5.84	0.041	16.	46.	130.	196.
1	RI	PROVIDENCE	5	14.22	0.044	43.	130.	394.	614.
1	RI	OTHER URBAN AREAS		14.22	0.044	43.	130.	394.	614.
1	RI	AVE. FOR STATE		14.22	0.044	43.	130.	394.	614.
1	VT	URBAN AREAS	5	4.75	0.041	13.	37.	104.	157.
1	VT	AVE. FOR STATE		4.75	0.041	13.	37.	104.	157.
1		AVE. FOR REGION 1		8.72	0.044	26.	77.	228.	354.
2	NJ	ATLANTIC CITY	5	0.0	0.0	0.	0.	0.	0.
2	NJ	NEW YORK CITY METRO	5	30.97	0.057	127.	524.	2153.	3791.
2	NJ	PHILADELPHIA METRO	5	6.88	0.042	19.	55.	156.	237.
2	NJ	TRENTON	5	0.0	0.0	0.	0.	0.	0.
2	NJ	VINELAND	5	0.0	0.0	0.	0.	0.	0.
2	NJ	AVE. FOR STATE		11.53	0.053	45.	165.	624.	1068.
2	NY	ALBANY	5	10.72	0.043	32.	94.	279.	432.
2	NY	BINGHAMPTON	5	5.47	0.041	15.	44.	123.	186.
2	NY	BUFFALO	5	14.30	0.045	44.	134.	410.	642.
2	NY	NEW YORK CITY	5	40.55	0.057	168.	691.	2840.	4999.
2	NY	ROCHESTER	5	12.78	0.045	39.	122.	368.	576.
2	NY	SYRACUSE	5	8.18	0.043	24.	69.	200.	305.
2	NY	UTICA	5	9.30	0.043	27.	78.	226.	346.
2	NY	OTHER URBAN AREAS		25.81	0.055	103.	404.	1606.	2797.
2	NY	AVE. FOR STATE		25.81	0.055	103.	404.	1606.	2797.
2		AVE. FOR REGION 2		24.45	0.055	97.	381.	1510.	2629.

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TABLE VI-9 ANNUAL CONTROL COSTS - URBANIZED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	FOR VI-20 CURVES. k	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
3	DE	WILMINGTON	5	9.98	0.043	29.	88.	288.	374.
3	DE	OTHER URBAN AREAS		9.94	0.043	29.	88.	288.	374.
3	DE	AVE. FOR STATE		9.94	0.043	29.	88.	288.	374.
3	DC	WASHINGTON,D.C.	5	28.97	0.057	119.	490.	2014.	3586.
3	DC	AVE. FOR STATE		28.97	0.057	119.	490.	2014.	3586.
3	MD	BALTIMORE	5	0.0	0.0	0.	0.	0.	0.
3	MD	WASHINGTON DC METRO	5	0.0	0.0	0.	0.	0.	0.
3	MD	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
3	MD	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
3	PA	ALLENTOWN	5	11.51	0.043	34.	100.	298.	453.
3	PA	ALTOONA	5	8.53	0.042	25.	71.	203.	310.
3	PA	ERIE	5	7.72	0.042	22.	64.	186.	284.
3	PA	HARRISBURG	5	10.67	0.043	32.	54.	278.	429.
3	PA	JOHNSTOWN	5	7.28	0.042	22.	58.	166.	257.
3	PA	LANCASTER	5	8.18	0.042	21.	67.	193.	298.
3	PA	PHILADELPHIA	5	13.02	0.048	36.	116.	346.	535.
3	PA	PITTSBURGH	5	22.05	0.048	75.	248.	810.	1317.
3	PA	READING	5	0.0	0.0	0.	0.	0.	0.
3	PA	SCRANTON	5	9.35	0.041	15.	61.	114.	172.
3	PA	WILKES-BARRE	5	8.36	0.043	28.	70.	203.	311.
3	PA	YORK	5	0.0	0.0	0.	0.	0.	0.
3	PA	OTHER URBAN AREAS		10.00	0.046	44.	141.	447.	711.
3	PA	AVE. FOR STATE		10.00	0.046	44.	141.	447.	711.
3	VA	LYNCHBURG	5	8.15	0.040	11.	31.	85.	127.
3	VA	NEWPORT NEWS	5	0.0	0.0	0.	0.	0.	0.
3	VA	NORFOLK	5	0.0	0.0	0.	0.	0.	0.
3	VA	PETERSBURG	5	0.0	0.0	0.	0.	0.	0.
3	VA	RICHMOND	5	10.24	0.043	30.	87.	254.	390.
3	VA	ROANOKE	5	8.08	0.042	23.	67.	192.	293.
3	VA	WASHINGTON DC METRO	5	10.87	0.044	45.	137.	415.	646.
3	VA	OTHER URBAN AREAS		8.10	0.043	24.	69.	199.	305.
3	VA	AVE. FOR STATE		8.10	0.043	24.	69.	199.	305.
3	WV	CHARLESTON	5	10.16	0.043	29.	85.	289.	361.
3	WV	HUNTINGTON	5	7.05	0.041	14.	38.	107.	168.
3	WV	STEUBENVILLE METRO	5	5.75	0.040	10.	27.	74.	110.
3	WV	WHEELING	5	6.33	0.042	18.	51.	148.	219.
3	WV	OTHER URBAN AREAS		6.01	0.042	17.	48.	136.	206.
3	WV	AVE. FOR STATE		6.01	0.042	17.	48.	136.	206.
3		AVE. FOR REGION 3		11.25	0.048	38.	124.	415.	676.

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TABLE VI-9 ANNUAL CONTROL COSTS - COMBINED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	FOR VI-20 COEFS. k	FOR VI-20 COEFS. B	CONTROL COST ($/ACRE) 25%	50%	75%	85%
4	AL	BIRMINGHAM	4	0.0	0.0	0.	0.	0.	0.
4	AL	GADSDEN	4	0.0	0.0	0.	0.	0.	0.
4	AL	HUNTSVILLE	4	0.0	0.0	0.	0.	0.	0.
4	AL	MOBILE	4	0.0	0.0	0.	0.	0.	0.
4	AL	MONTGOMERY	4	0.0	0.0	0.	0.	0.	0.
4	AL	TUSCALOOSA	4	0.0	0.0	0.	0.	0.	0.
4	AL	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
4	AL	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
4	FL	FT.LAUDERDALE	4	0.0	0.0	0.	0.	0.	0.
4	FL	GAINESVILLE	4	0.0	0.0	0.	0.	0.	0.
4	FL	JACKSONVILLE	4	0.0	0.0	0.	0.	0.	0.
4	FL	MIAMI	4	0.0	0.0	0.	0.	0.	0.
4	FL	ORLANDO	4	18.99	0.041	53.	146.	406.	610.
4	FL	PENSACOLA	4	0.0	0.0	0.	0.	0.	0.
4	FL	ST.PETERSBURG	4	0.0	0.0	0.	0.	0.	0.
4	FL	TALLAHASSEE	4	0.0	0.0	0.	0.	0.	0.
4	FL	TAMPA	4	0.0	0.0	0.	0.	0.	0.
4	FL	WEST PALM BEACH	4	0.0	0.0	0.	0.	0.	0.
4	FL	OTHER URBAN AREAS		18.99	0.041	53.	146.	406.	610.
4	FL	AVE. FOR STATE		18.99	0.041	53.	146.	406.	610.
4	GA	ALBANY	4	5.68	0.038	15.	37.	97.	141.
4	GA	ATLANTA	4	11.79	0.040	32.	86.	213.	307.
4	GA	AUGUSTA	4	5.97	0.039	16.	41.	108.	158.
4	GA	COLUMBUS	4	11.63	0.040	31.	84.	228.	336.
4	GA	MACON	4	0.0	0.0	0.	0.	0.	0.
4	GA	SAVANNAH	4	22.70	0.041	64.	180.	505.	762.
4	GA	OTHER URBAN AREAS		10.42	0.040	28.	77.	208.	310.
4	GA	AVE. FOR STATE		10.42	0.040	28.	77.	208.	310.
4	KY	HUNTINGTON METRO	5	7.48	0.042	21.	61.	176.	249.
4	KY	LEXINGTON	5	0.0	0.0	0.	0.	0.	0.
4	KY	LOUISVILLE	5	11.83	0.044	35.	104.	313.	479.
4	KY	OWENSBORO	5	8.87	0.042	24.	70.	201.	307.
4	KY	OTHER URBAN AREAS		9.28	0.043	27.	79.	228.	350.
4	KY	AVE. FOR STATE		9.28	0.043	27.	79.	228.	350.
4	MS	BILOXI	4	0.0	0.0	0.	0.	0.	0.
4	MS	JACKSON	4	0.0	0.0	0.	0.	0.	0.
4	MS	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
4	MS	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
4	NC	ASHEVILLE	4	0.0	0.0	0.	0.	0.	0.
4	NC	CHARLOTTE	4	0.0	0.0	0.	0.	0.	0.
4	NC	DURHAM	4	0.0	0.0	0.	0.	0.	0.
4	NC	FAYETTEVILLE	4	0.0	0.0	0.	0.	0.	0.
4	NC	GREENSBORO	4	0.0	0.0	0.	0.	0.	0.
4	NC	HIGHPOINT	4	0.0	0.0	0.	0.	0.	0.
4	NC	RALEIGH	4	0.0	0.0	0.	0.	0.	0.
4	NC	WILMINGTON	4	0.0	0.0	0.	0.	0.	0.
4	NC	WINSTON-SALEM	4	0.0	0.0	0.	0.	0.	0.
4	NC	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
4	NC	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
4	SC	CHARLESTON	4	0.0	0.0	0.	0.	0.	0.
4	SC	COLUMBIA	4	0.0	0.0	0.	0.	0.	0.
4	SC	GREENVILLE	4	0.0	0.0	0.	0.	0.	0.
4	SC	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
4	SC	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
4	TN	CHATTANOOGA	4	13.92	0.040	38.	102.	277.	412.
4	TN	KNOXVILLE	4	0.0	0.0	0.	0.	0.	0.
4	TN	MEMPHIS	4	0.0	0.0	0.	0.	0.	0.
4	TN	NASHVILLE	4	12.68	0.040	35.	94.	256.	383.
4	TN	OTHER URBAN AREAS		12.85	0.040	35.	95.	259.	387.
4	TN	AVE. FOR STATE		12.85	0.040	35.	95.	259.	387.
4		AVE. FOR REGION 4		10.98	0.040	30.	82.	225.	336.

TABLE VI-9 ANNUAL CONTROL COSTS - COMBINED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. B	CONTROL COST ($/ACRE) 25%	50%	75%	85%
5	IL	AURORA	3	0.0	0.0	0.	0.	0.	0.
5	IL	BLOOMINGTON	3	0.0	0.0	0.	0.	0.	0.
5	IL	CHAMPAIGN	3	0.0	0.0	0.	0.	0.	0.
5	IL	CHICAGO	3	26.48	0.047	85.	271.	867.	1380.
5	IL	DAVENPORT METRO	3	7.18	0.039	19.	51.	134.	198.
5	IL	DECATUR	3	6.19	0.038	16.	42.	110.	162.
5	IL	JOLIET	3	0.0	0.0	0.	0.	0.	0.
5	IL	PEORIA	3	5.53	0.038	14.	37.	97.	143.
5	IL	ROCKFORD	3	0.0	0.0	0.	0.	0.	0.
5	IL	SPRINGFIELD	3	9.10	0.040	25.	66.	178.	266.
5	IL	OTHER URBAN AREAS		23.86	0.046	76.	242.	771.	1225.
5	IL	AVE. FOR STATE		23.86	0.046	76.	242.	771.	1225.
5	IN	ANDERSON	3	3.16	0.037	8.	20.	49.	71.
5	IN	CHICAGO METRO	3	12.48	0.041	35.	96.	266.	400.
5	IN	EVANSVILLE	3	7.67	0.039	20.	53.	140.	205.
5	IN	FORT WAYNE	3	13.11	0.041	36.	101.	281.	423.
5	IN	INDIANAPOLIS	3	13.98	0.041	39.	106.	292.	438.
5	IN	LAFAYETTE	3	14.12	0.041	39.	110.	307.	462.
5	IN	MUNCIE	3	8.36	0.039	22.	59.	156.	230.
5	IN	SOUTH BEND	3	6.38	0.039	17.	44.	115.	169.
5	IN	TERRA HAUTE	3	0.0	0.0	0.	0.	0.	0.
5	IN	OTHER URBAN AREAS		10.04	0.040	27.	75.	204.	305.
5	IN	AVE. FOR STATE		10.04	0.040	27.	75.	204.	305.
5	MI	ANN ARBOR	3	0.0	0.0	0.	0.	0.	0.
5	MI	BAY CITY	3	4.85	0.039	13.	33.	87.	128.
5	MI	DETROIT	3	13.12	0.041	37.	103.	289.	437.
5	MI	FLINT	3	8.61	0.040	23.	63.	172.	256.
5	MI	GRAND RAPIDS	3	10.83	0.041	30.	82.	227.	340.
5	MI	JACKSON	3	6.16	0.039	16.	42.	111.	164.
5	MI	KALAMAZOO	3	0.0	0.0	0.	0.	0.	0.
5	MI	LANSING	3	8.67	0.040	23.	64.	172.	256.
5	MI	MUSKEGON	3	0.0	0.0	0.	0.	0.	0.
5	MI	SAGINAW	3	5.12	0.039	13.	35.	93.	137.
5	MI	OTHER URBAN AREAS		12.05	0.041	34.	94.	262.	396.
5	MI	AVE. FOR STATE		12.05	0.041	34.	94.	262.	396.
5	MN	DULUTH	3	8.42	0.040	23.	62.	169.	251.
5	MN	FARGO METRO	3	4.45	0.039	12.	31.	83.	122.
5	MN	MINNEAPOLIS	3	7.72	0.040	21.	57.	157.	234.
5	MN	ROCHESTER	3	0.0	0.0	0.	0.	0.	0.
5	MN	OTHER URBAN AREAS		7.56	0.040	21.	56.	153.	229.
5	MN	AVE. FOR STATE		7.56	0.040	21.	56.	153.	229.
5	OH	AKRON	3	0.0	0.0	0.	0.	0.	0.
5	OH	CANTON	3	17.56	0.042	50.	140.	397.	602.
5	OH	CINCINNATI	3	8.00	0.039	21.	57.	153.	226.
5	OH	CLEVELAND	3	17.43	0.042	50.	145.	419.	640.
5	OH	COLUMBUS	3	17.08	0.042	48.	137.	390.	592.
5	OH	DAYTON	3	0.0	0.0	0.	0.	0.	0.
5	OH	HAMILTON	3	16.66	0.041	47.	130.	365.	550.
5	OH	LIMA	3	4.94	0.038	13.	33.	85.	124.
5	OH	LORAIN	3	35.15	0.056	142.	578.	2342.	4099.
5	OH	MANSFIELD	3	0.0	0.0	0.	0.	0.	0.
5	OH	SPRINGFIELD	3	8.48	0.039	22.	60.	158.	234.
5	OH	STEUBENVILLE	3	9.61	0.039	26.	69.	184.	273.
5	OH	TOLEDO	3	10.31	0.040	28.	77.	211.	316.
5	OH	YOUNGSTOWN	3	12.96	0.040	35.	96.	263.	392.
5	OH	OTHER URBAN AREAS		11.26	0.041	31.	87.	242.	365.
5	OH	AVE. FOR STATE		11.26	0.041	31.	87.	242.	365.
5	WI	APPLETON	3	11.40	0.041	32.	88.	246.	371.
5	WI	DULUTH METRO	3	0.0	0.0	0.	0.	0.	0.
5	WI	GREEN BAY	3	6.44	0.039	17.	46.	124.	183.
5	WI	KENOSHA	3	11.95	0.041	33.	92.	254.	382.
5	WI	LA CROSSE	3	7.90	0.040	21.	57.	153.	228.
5	WI	MADISON	3	0.0	0.0	0.	0.	0.	0.
5	WI	MILWAUKEE	3	23.24	0.050	80.	277.	957.	1571.
5	WI	OSHKOSH	3	0.0	0.0	0.	0.	0.	0.
5	WI	RACINE	3	0.0	0.0	0.	0.	0.	0.
5	WI	OTHER URBAN AREAS		20.32	0.049	69.	235.	799.	1305.
5	WI	AVE. FOR STATE		20.32	0.049	69.	235.	799.	1305.
5		AVE. FOR REGION 5		15.06	0.044	46.	137.	416.	650.

TABLE VI-9 ANNUAL CONTROL COSTS - COMBINED AREAS

EPA RFG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. B	CONTROL COST ($/ACRE) 25%	50%	75%	85%
6	AR	FORT SMITH	4	5.52	0.038	14.	37.	96.	181.
6	AR	LITTLE ROCK	4	0.0	0.0	0.	0.	0.	0.
6	AR	PINE BLUFF	4	0.0	0.0	0.	0.	0.	0.
6	AR	OTHER URBAN AREAS		5.52	0.038	14.	37.	96.	181.
6	AR	AVE. FOR STATE		5.52	0.038	14.	37.	96.	181.
6	LA	BATON ROUGE	4	0.0	0.0	0.	0.	0.	0.
6	LA	LAFAYETTE	4	0.0	0.0	0.	0.	0.	0.
6	LA	LAKE CHARLES	4	0.0	0.0	0.	0.	0.	0.
6	LA	MONROE	4	0.0	0.0	0.	0.	0.	0.
6	LA	NEW ORLEANS	4	0.0	0.0	0.	0.	0.	0.
6	LA	SHREVEPORT	4	0.0	0.0	0.	0.	0.	0.
6	LA	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
6	LA	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
6	NM	ALBUQUERQUE	2	0.0	0.0	0.	0.	0.	0.
6	NM	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
6	NM	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
6	OK	LAWTON	3	0.0	0.0	0.	0.	0.	0.
6	OK	OKLAHOMA CITY	3	0.0	0.0	0.	0.	0.	0.
6	OK	TULSA	3	0.0	0.0	0.	0.	0.	0.
6	OK	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
6	OK	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
6	TX	ABILENE	3	0.0	0.0	0.	0.	0.	0.
6	TX	AMARILLO	3	0.0	0.0	0.	0.	0.	0.
6	TX	AUSTIN	3	0.0	0.0	0.	0.	0.	0.
6	TX	BEAUMONT	3	0.0	0.0	0.	0.	0.	0.
6	TX	BROWNSVILLE	3	18.62	0.040	51.	141.	347.	581.
6	TX	BRYAN	3	0.0	0.0	0.	0.	0.	0.
6	TX	CORPUS CHRISTI	3	0.0	0.0	0.	0.	0.	0.
6	TX	DALLAS	3	0.0	0.0	0.	0.	0.	0.
6	TX	EL PASO	3	0.0	0.0	0.	0.	0.	0.
6	TX	FORT WORTH	3	0.0	0.0	0.	0.	0.	0.
6	TX	GALVESTON	3	0.0	0.0	0.	0.	0.	0.
6	TX	HARLINGEN	3	37.77	0.056	153.	621.	2516.	8804.
6	TX	HOUSTON	3	0.0	0.0	0.	0.	0.	0.
6	TX	LAREDO	3	38.09	0.052	140.	512.	1877.	3157.
6	TX	LUBBOCK	3	0.0	0.0	0.	0.	0.	0.
6	TX	MCALLEN	3	0.0	0.0	0.	0.	0.	0.
6	TX	MIDLAND	3	0.0	0.0	0.	0.	0.	0.
6	TX	ODESSA	3	0.0	0.0	0.	0.	0.	0.
6	TX	PORT ARTHUR	3	0.0	0.0	0.	0.	0.	0.
6	TX	SAN ANGELO	3	0.0	0.0	0.	0.	0.	0.
6	TX	SAN ANTONIO	3	0.0	0.0	0.	0.	0.	0.
6	TX	SHERMAN	3	0.0	0.0	0.	0.	0.	0.
6	TX	TEXARKANA	3	0.0	0.0	0.	0.	0.	0.
6	TX	TEXAS CITY	3	0.0	0.0	0.	0.	0.	0.
6	TX	TYLER	3	0.0	0.0	0.	0.	0.	0.
6	TX	WACO	3	0.0	0.0	0.	0.	0.	0.
6	TX	WICHITA FALL	3	0.0	0.0	0.	0.	0.	0.
6	TX	OTHER URBAN AREAS		22.50	0.051	80.	277.	992.	1665.
6	TX	AVE. FOR STATE		22.50	0.051	80.	277.	992.	1665.
6		AVE. FOR REGION 6		10.34	0.048	35.	111.	371.	608.

TABLE VI-9 ANNUAL CONTROL COSTS - COMBINED AREAS

EPA REG	STATE ID	URBANIZED AREA	HCF CTY	FOR VI-20 COEFS. k	FOR VI-20 COEFS. β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
7	IA	CEDAR RAPIDS	3	0.0	0.0	0.	0.	0.	0.
7	IA	DAVENPORT	3	9.61	0.040	26.	71.	191.	285.
7	IA	DES MOINES	3	25.07	0.056	101.	405.	1628.	2839.
7	IA	DUBUQUE	3	0.0	0.0	0.	0.	0.	0.
7	IA	SIOUX CITY	3	0.0	0.0	0.	0.	0.	0.
7	IA	WATERLOO	3	0.0	0.0	0.	0.	0.	0.
7	IA	OTHER URBAN AREAS		28.05	0.055	96.	385.	1542.	2688.
7	IA	AVE. FOR STATE		28.05	0.055	96.	385.	1542.	2688.
7	KS	KANSAS CITY METRO	3	9.53	0.040	26.	70.	189.	282.
7	KS	TOPEKA	3	9.97	0.040	27.	73.	199.	297.
7	KS	WICHITA	3	0.0	0.0	0.	0.	0.	0.
7	KS	OTHER URBAN AREAS		9.68	0.040	26.	71.	193.	287.
7	KS	AVE. FOR STATE		9.68	0.040	26.	71.	193.	287.
7	MO	COLUMBIA	3	0.0	0.0	0.	0.	0.	0.
7	MO	KANSAS CITY	3	10.01	0.041	39.	109.	306.	462.
7	MO	SPRINGFIELD	3	0.0	0.0	0.	0.	0.	0.
7	MO	ST.JOSEPH	3	3.77	0.037	10.	24.	61.	89.
7	MO	ST.LOUIS	3	7.69	0.039	20.	54.	143.	211.
7	MO	OTHER URBAN AREAS		8.19	0.039	22.	59.	158.	235.
7	MO	AVE. FOR STATE		8.19	0.039	22.	59.	158.	235.
7	NE	LINCOLN	3	0.0	0.0	0.	0.	0.	0.
7	NE	OMAHA	3	9.98	0.041	28.	77.	214.	322.
7	NE	OTHER URBAN AREAS		9.98	0.041	28.	77.	214.	322.
7	NE	AVE. FOR STATE		9.98	0.041	28.	77.	214.	322.
7		AVE. FOR REGION 7		8.80	0.043	26.	75.	224.	349.
8	CO	BOULDER	2	0.0	0.0	0.	0.	0.	0.
8	CO	COLORADO SPRINGS	2	0.0	0.0	0.	0.	0.	0.
8	CO	DENVER	2	19.37	0.051	69.	247.	882.	1468.
8	CO	PUEBLO	2	10.42	0.041	41.	114.	322.	488.
8	CO	OTHER URBAN AREAS		15.04	0.045	46.	141.	434.	684.
8	CO	AVE. FOR STATE		15.04	0.045	46.	141.	434.	684.
8	MT	BILLINGS	2	0.0	0.0	0.	0.	0.	0.
8	MT	GREAT FALLS	2	0.0	0.0	0.	0.	0.	0.
8	MT	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
8	MT	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
8	ND	FARGO	3	8.93	0.039	13.	35.	94.	140.
8	ND	OTHER URBAN AREAS		8.93	0.039	13.	35.	94.	140.
8	ND	AVE. FOR STATE		8.93	0.039	13.	35.	94.	140.
8	SD	SIOUX FALLS	3	7.36	0.040	20.	54.	148.	221.
8	SD	OTHER URBAN AREAS		7.36	0.040	20.	54.	148.	221.
8	SD	AVE. FOR STATE		7.36	0.040	20.	54.	148.	221.
8	UT	OGDEN	2	0.0	0.0	0.	0.	0.	0.
8	UT	PROVO	2	0.0	0.0	0.	0.	0.	0.
8	UT	SALT LAKE CITY	2	0.0	0.0	0.	0.	0.	0.
8	UT	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
8	UT	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
8	WY	URBAN AREAS	2	0.0	0.0	0.	0.	0.	0.
8	WY	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
8		AVE. FOR REGION 8		10.72	0.044	32.	95.	286.	445.

TABLE VI-9 ANNUAL CONTROL COSTS - COMBINED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQ. VI-20 COEFS. k	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
9	AK	URBAN AREAS	1	14.83	0.040	40.	107.	287.	476.
9	AK	AVE. FOR STATE		14.83	0.040	40.	107.	287.	476.
9	AZ	PHOENIX	2	0.0	0.0	0.	0.	0.	0.
9	AZ	TUCSON	5	0.0	0.0	0.	0.	0.	0.
9	AZ	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
9	AZ	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
9	CA	BAKERSFIELD	1	0.0	0.0	0.	0.	0.	0.
9	CA	FRESNO	1	0.0	0.0	0.	0.	0.	0.
9	CA	LOS ANGELES	1	0.0	0.0	0.	0.	0.	0.
9	CA	MODESTO	1	0.0	0.0	0.	0.	0.	0.
9	CA	OXNARD	1	0.0	0.0	0.	0.	0.	0.
9	CA	SACRAMENTO	1	7.29	0.039	19.	52.	138.	205.
9	CA	SALINAS	1	0.0	0.0	0.	0.	0.	0.
9	CA	SAN BERNARDINO	1	0.0	0.0	0.	0.	0.	0.
9	CA	SAN DIEGO	1	0.0	0.0	0.	0.	0.	0.
9	CA	SAN FRANCISCO	1	27.64	0.045	86.	267.	829.	1308.
9	CA	SAN JOSE	1	0.0	0.0	0.	0.	0.	0.
9	CA	SANTA BARBARA	1	0.0	0.0	0.	0.	0.	0.
9	CA	SANTA ROSA	1	0.0	0.0	0.	0.	0.	0.
9	CA	SEASIDE	1	0.0	0.0	0.	0.	0.	0.
9	CA	SIMI VALLEY	1	0.0	0.0	0.	0.	0.	0.
9	CA	STOCKTON	1	0.0	0.0	0.	0.	0.	0.
9	CA	OTHER URBAN AREAS		25.70	0.045	80.	247.	768.	1201.
9	CA	AVE. FOR STATE		25.70	0.045	80.	247.	768.	1201.
9	HI	HONOLULU	1	0.0	0.0	0.	0.	0.	0.
9	HI	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
9	HI	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
9	NV	LAS VEGAS	2	0.0	0.0	0.	0.	0.	0.
9	NV	RENO	2	5.22	0.039	14.	36.	96.	142.
9	NV	OTHER URBAN AREAS		5.22	0.039	14.	36.	96.	142.
9	NV	AVE. FOR STATE		5.22	0.039	14.	36.	96.	142.
9		AVE. FOR REGION 9		24.76	0.045	77.	237.	732.	1150.
10	ID	BOISE	2	0.0	0.0	0.	0.	0.	0.
10	ID	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
10	ID	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
10	OR	EUGENE	1	14.71	0.039	39.	104.	277.	409.
10	OR	PORTLAND	1	18.01	0.039	48.	129.	345.	511.
10	OR	SALEM	1	0.0	0.0	0.	0.	0.	0.
10	OR	OTHER URBAN AREAS		17.94	0.039	48.	128.	343.	509.
10	OR	AVE. FOR STATE		17.94	0.039	48.	128.	343.	509.
10	WA	SEATTLE	1	14.99	0.039	40.	107.	285.	423.
10	WA	SPOKANE	1	3.69	0.038	10.	25.	65.	96.
10	WA	TACOMA	1	16.08	0.039	43.	114.	305.	451.
10	WA	OTHER URBAN AREAS		11.22	0.039	30.	80.	212.	314.
10	WA	AVE. FOR STATE		11.22	0.039	30.	80.	212.	314.
10		AVE. FOR REGION 10		13.17	0.039	35.	94.	250.	370.
		AVERAGE FOR THE U.S.		14.05	0.048	47.	151.	501.	815.

TABLE VI-10 ANNUAL CONTROL COSTS - STORM AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. B	CONTROL COST ($/ACRE) 25%	CONTROL COST ($/ACRE) 50%	CONTROL COST ($/ACRE) 75%	CONTROL COST ($/ACRE) 85%
1	CT	BRIDGEPORT	5	9.46	0.043	28.	80.	233.	358.
1	CT	BRISTOL	5	11.75	0.043	35.	103.	304.	469.
1	CT	DANBURY	5	9.07	0.043	26.	76.	222.	339.
1	CT	HARTFORD	5	10.65	0.043	31.	92.	270.	416.
1	CT	MERIDEN	5	10.39	0.043	30.	88.	258.	398.
1	CT	NEW BRITAIN	5	8.35	0.042	24.	69.	199.	303.
1	CT	NEW HAVEN	5	9.21	0.043	28.	81.	234.	358.
1	CT	NORWALK	5	4.26	0.039	9.	23.	64.	89.
1	CT	STAMFORD	5	8.64	0.043	26.	81.	233.	359.
1	CT	WATERBURY	5	10.48	0.043	31.	89.	259.	397.
1	CT	OTHER URBAN AREAS		9.36	0.043	27.	79.	230.	352.
1	CT	AVE. FOR STATE		9.36	0.043	27.	79.	230.	352.
1	ME	LEWISTON	5	0.0	0.0	0.	0.	0.	0.
1	ME	PORTLAND	5	0.0	0.0	0.	0.	0.	0.
1	ME	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
1	ME	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
1	MA	BOSTON	5	15.23	0.044	46.	139.	422.	657.
1	MA	BROCKTON	5	10.17	0.043	30.	86.	251.	385.
1	MA	FALL RIVER	5	10.61	0.043	31.	91.	264.	406.
1	MA	FITCHBURG	5	10.21	0.043	30.	86.	251.	384.
1	MA	LAWRENCE	5	0.0	0.0	0.	0.	0.	0.
1	MA	LOWELL	5	11.08	0.043	33.	97.	288.	444.
1	MA	NEW BEDFORD	5	7.92	0.042	23.	65.	188.	287.
1	MA	PITTSFIELD	5	10.35	0.043	30.	88.	258.	396.
1	MA	SPRINGFIELD	5	0.0	0.0	0.	0.	0.	0.
1	MA	WORCESTER	5	8.62	0.042	25.	71.	203.	310.
1	MA	OTHER URBAN AREAS		14.01	0.044	42.	127.	381.	592.
1	MA	AVE. FOR STATE		14.01	0.044	42.	127.	381.	592.
1	NH	MANCHESTER	5	0.0	0.0	0.	0.	0.	0.
1	NH	NASHUA	5	0.0	0.0	0.	0.	0.	0.
1	NH	OTHER URBAN AREAS		0.0	0.0	0.	0.	0.	0.
1	NH	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
1	RI	PROVIDENCE	5	8.09	0.042	23.	67.	195.	297.
1	RI	OTHER URBAN AREAS		8.09	0.042	23.	67.	195.	297.
1	RI	AVE. FOR STATE		8.09	0.042	23.	67.	195.	297.
1	VT	URBAN AREAS	5	0.0	0.0	0.	0.	0.	0.
1	VT	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
1		AVE. FOR REGION 1		12.03	0.044	36.	107.	318.	491.
2	NJ	ATLANTIC CITY	5	11.62	0.043	34.	102.	301.	465.
2	NJ	NEW YORK CITY METRO	5	14.09	0.044	42.	127.	382.	593.
2	NJ	PHILADELPHIA METRO	5	0.0	0.0	0.	0.	0.	0.
2	NJ	TRENTON	5	8.09	0.042	23.	67.	192.	293.
2	NJ	VINELAND	5	7.87	0.042	22.	64.	184.	279.
2	NJ	AVE. FOR STATE		13.54	0.044	41.	122.	364.	565.
2	NY	ALBANY	5	10.72	0.043	32.	94.	279.	432.
2	NY	BINGHAMPTON	5	0.0	0.0	0.	0.	0.	0.
2	NY	BUFFALO	5	5.15	0.041	14.	41.	114.	175.
2	NY	NEW YORK CITY	5	29.81	0.055	119.	477.	1908.	3322.
2	NY	ROCHESTER	5	12.78	0.045	39.	120.	368.	578.
2	NY	SYRACUSE	5	8.18	0.043	24.	69.	200.	305.
2	NY	UTICA	5	9.30	0.043	27.	78.	226.	346.
2	NY	OTHER URBAN AREAS		21.90	0.055	86.	335.	1313.	2271.
2	NY	AVE. FOR STATE		21.90	0.055	86.	335.	1313.	2271.
2		AVE. FOR REGION 2		16.72	0.051	61.	216.	786.	1323.

TABLE VI-10 ANNUAL CONTROL COSTS - STORM AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. β	CONTROL COST ($/ACRE) 25%	CONTROL COST ($/ACRE) 50%	CONTROL COST ($/ACRE) 75%	CONTROL COST ($/ACRE) 85%
3	DE	WILMINGTON	5	9.94	0.043	29.	84.	244.	374.
3	DE	OTHER URBAN AREAS		9.94	0.043	29.	84.	244.	374.
3	DE	AVE. FOR STATE		9.94	0.043	29.	84.	244.	374.
3	DC	WASHINGTON,D.C.	5	11.86	0.044	35.	105.	311.	481.
3	DC	AVE. FOR STATE		11.86	0.044	35.	105.	311.	481.
3	MD	BALTIMORE	5	10.93	0.043	32.	94.	277.	427.
3	MD	WASHINGTON DC METRO	5	11.07	0.043	33.	97.	285.	440.
3	MD	OTHER URBAN AREAS		10.96	0.043	32.	95.	279.	430.
3	MD	AVE. FOR STATE		10.96	0.043	32.	95.	279.	430.
3	PA	ALLENTOWN	5	11.51	0.043	34.	100.	294.	453.
3	PA	ALTOONA	5	8.53	0.043	25.	71.	203.	310.
3	PA	ERIE	5	7.13	0.042	20.	59.	168.	257.
3	PA	HARRISBURG	5	10.67	0.043	32.	94.	278.	429.
3	PA	JOHNSTOWN	5	7.28	0.042	21.	58.	166.	252.
3	PA	LANCASTER	5	8.14	0.042	24.	67.	193.	296.
3	PA	PHILADELPHIA	5	10.05	0.043	29.	86.	250.	384.
3	PA	PITTSBURGH	5	22.83	0.048	75.	248.	818.	1317.
3	PA	READING	5	8.10	0.042	23.	67.	192.	294.
3	PA	SCRANTON	5	0.0	0.0	0.	0.	0.	0.
3	PA	WILKES-BARRE	5	8.35	0.043	24.	70.	203.	311.
3	PA	YORK	5	7.06	0.042	20.	58.	164.	250.
3	PA	OTHER URBAN AREAS		11.15	0.044	34.	101.	305.	474.
3	PA	AVE. FOR STATE		11.15	0.044	34.	101.	305.	474.
3	VA	LYNCHBURG	5	0.0	0.0	0.	0.	0.	0.
3	VA	NEWPORT NEWS	5	10.68	0.043	31.	91.	267.	409.
3	VA	NORFOLK	5	13.56	0.044	40.	120.	359.	555.
3	VA	PETERSBURG	5	13.29	0.044	40.	119.	354.	549.
3	VA	RICHMOND	5	10.24	0.043	30.	87.	254.	390.
3	VA	ROANOKE	5	8.08	0.042	23.	67.	192.	293.
3	VA	WASHINGTON DC METRO	5	11.66	0.044	35.	103.	305.	471.
3	VA	OTHER URBAN AREAS		11.79	0.043	35.	103.	306.	473.
3	VA	AVE. FOR STATE		11.79	0.043	35.	103.	306.	473.
3	WV	CHARLESTON	5	10.10	0.043	29.	85.	249.	381.
3	WV	HUNTINGTON	5	0.0	0.0	0.	0.	0.	0.
3	WV	STEUBENVILLE METRO	5	0.0	0.0	0.	0.	0.	0.
3	WV	WHEELING	5	6.33	0.042	18.	51.	144.	219.
3	WV	OTHER URBAN AREAS		9.61	0.043	28.	81.	235.	360.
3	WV	AVE. FOR STATE		9.61	0.043	28.	81.	235.	360.
3		AVE. FOR REGION 3		11.21	0.044	33.	100.	298.	461.

TABLE VI-10 ANNUAL CONTROL COSTS - STORM AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	B	CONTROL COST ($/ACRE) 25%	50%	75%	85%
4	AL	BIRMINGHAM	4	13.48	0.040	36.	99.	267.	398.
4	AL	GADSDEN	4	15.20	0.040	42.	113.	308.	460.
4	AL	HUNTSVILLE	4	14.90	0.040	41.	111.	302.	451.
4	AL	MOBILE	4	19.19	0.040	52.	142.	388.	579.
4	AL	MONTGOMERY	4	14.98	0.040	41.	111.	302.	450.
4	AL	TUSCALOOSA	4	10.53	0.039	28.	75.	199.	295.
4	AL	OTHER URBAN AREAS		14.92	0.040	40.	110.	298.	445.
4	AL	AVE. FOR STATE		14.92	0.040	40.	110.	298.	445.
4	FL	FT.LAUDERDALE	4	19.12	0.040	53.	144.	396.	593.
4	FL	GAINESVILLE	4	12.49	0.040	34.	91.	245.	364.
4	FL	JACKSONVILLE	4	14.88	0.040	41.	110.	300.	448.
4	FL	MIAMI	4	18.34	0.040	50.	137.	376.	563.
4	FL	ORLANDO	4	18.79	0.041	53.	146.	406.	610.
4	FL	PENSACOLA	4	18.62	0.040	51.	139.	380.	567.
4	FL	ST.PETERSBURG	4	20.03	0.041	55.	154.	426.	640.
4	FL	TALLAHASSEE	4	17.78	0.040	49.	134.	366.	548.
4	FL	TAMPA	4	21.22	0.041	59.	166.	462.	697.
4	FL	WEST PALM BEACH	4	17.37	0.040	47.	129.	350.	523.
4	FL	OTHER URBAN AREAS		18.33	0.040	50.	138.	380.	570.
4	FL	AVE. FOR STATE		18.33	0.040	50.	138.	380.	570.
4	GA	ALBANY	4	0.0	0.0	0.	0.	0.	0.
4	GA	ATLANTA	4	11.79	0.040	32.	86.	233.	347.
4	GA	AUGUSTA	4	0.0	0.0	0.	0.	0.	0.
4	GA	COLUMBUS	4	11.63	0.040	31.	84.	228.	338.
4	GA	MACON	4	12.03	0.040	33.	89.	242.	361.
4	GA	SAVANNAH	4	4.98	0.037	13.	32.	82.	119.
4	GA	OTHER URBAN AREAS		11.57	0.040	31.	84.	228.	340.
4	GA	AVE. FOR STATE		11.57	0.040	31.	84.	228.	340.
4	KY	HUNTINGTON METRO	5	7.48	0.042	21.	61.	176.	269.
4	KY	LEXINGTON	5	8.78	0.042	25.	73.	210.	321.
4	KY	LOUISVILLE	5	11.83	0.044	35.	104.	310.	479.
4	KY	OWENSBORO	5	8.47	0.042	24.	70.	201.	307.
4	KY	OTHER URBAN AREAS		10.97	0.043	32.	96.	282.	435.
4	KY	AVE. FOR STATE		10.97	0.043	32.	96.	282.	435.
4	MS	BILOXI	4	13.68	0.040	37.	99.	267.	397.
4	MS	JACKSON	4	13.63	0.040	37.	100.	273.	407.
4	MS	OTHER URBAN AREAS		13.65	0.040	37.	100.	271.	403.
4	MS	AVE. FOR STATE		13.65	0.040	37.	100.	271.	403.
4	NC	ASHEVILLE	4	16.69	0.041	46.	127.	352.	528.
4	NC	CHARLOTTE	4	10.18	0.040	27.	74.	199.	296.
4	NC	DURHAM	4	8.94	0.039	24.	64.	171.	253.
4	NC	FAYETTEVILLE	4	11.35	0.040	31.	83.	223.	331.
4	NC	GREENSBORO	4	12.31	0.040	34.	92.	251.	375.
4	NC	HIGHPOINT	4	8.70	0.039	23.	62.	164.	242.
4	NC	RALEIGH	4	12.58	0.040	34.	93.	253.	377.
4	NC	WILMINGTON	4	18.98	0.041	53.	146.	404.	607.
4	NC	WINSTON-SALEM	4	11.31	0.040	30.	82.	222.	330.
4	NC	OTHER URBAN AREAS		11.69	0.040	32.	86.	233.	348.
4	NC	AVE. FOR STATE		11.69	0.040	32.	86.	233.	348.
4	SC	CHARLESTON	4	11.08	0.040	30.	80.	216.	322.
4	SC	COLUMBIA	4	11.79	0.040	32.	86.	233.	347.
4	SC	GREENVILLE	4	11.11	0.040	30.	81.	218.	324.
4	SC	OTHER URBAN AREAS		11.36	0.040	31.	83.	223.	332.
4	SC	AVE. FOR STATE		11.36	0.040	31.	83.	223.	332.
4	TN	CHATTANOOGA	4	13.92	0.040	38.	102.	277.	412.
4	TN	KNOXVILLE	4	11.45	0.040	31.	84.	226.	336.
4	TN	MEMPHIS	4	17.71	0.041	49.	136.	378.	568.
4	TN	NASHVILLE	4	8.88	0.039	24.	63.	168.	248.
4	TN	OTHER URBAN AREAS		14.74	0.040	40.	111.	305.	458.
4	TN	AVE. FOR STATE		14.74	0.040	40.	111.	305.	458.
4		AVE. FOR REGION 4		14.58	0.040	40.	110.	303.	454.

TABLE VI-10 ANNUAL CONTROL COSTS - STORM AREAS

EPA REG	STATE ID	URBANIZED AREA	DFF CTY	FOR VI-20 COEFFS. k	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
5	IL	AURORA	3	12.80	0.041	36.	98.	273.	410.
5	IL	BLOOMINGTON	3	12.52	0.041	34.	95.	261.	392.
5	IL	CHAMPAIGN	3	11.80	0.040	32.	88.	241.	361.
5	IL	CHICAGO	3	3.20	0.037	8.	20.	51.	74.
5	IL	DAVENPORT METRO	3	7.16	0.039	19.	51.	138.	198.
5	IL	DECATUR	3	0.0	0.0	0.	0.	0.	0.
5	IL	JOLIET	3	10.24	0.040	28.	76.	218.	311.
5	IL	PEORIA	3	0.0	0.0	0.	0.	0.	0.
5	IL	ROCKFORD	3	14.05	0.041	39.	109.	302.	455.
5	IL	SPRINGFIELD	3	9.10	0.040	25.	66.	178.	260.
5	IL	OTHER URBAN AREAS		5.80	0.039	15.	41.	110.	164.
5	IL	AVE. FOR STATE		5.80	0.039	15.	41.	110.	164.
5	IN	ANDERSON	3	0.0	0.0	0.	0.	0.	0.
5	IN	CHICAGO METRO	3	12.48	0.041	35.	96.	266.	400.
5	IN	EVANSVILLE	3	0.0	0.0	0.	0.	0.	0.
5	IN	FORT WAYNE	3	13.11	0.041	36.	101.	281.	423.
5	IN	INDIANAPOLIS	3	13.96	0.041	39.	106.	292.	438.
5	IN	LAFAYETTE	3	2.17	0.036	5.	13.	32.	46.
5	IN	MUNCIE	3	8.34	0.039	22.	59.	156.	230.
5	IN	SOUTH BEND	3	0.0	0.0	0.	0.	0.	0.
5	IN	TERRE HAUTE	3	8.87	0.039	24.	63.	166.	248.
5	IN	OTHER URBAN AREAS		11.63	0.041	32.	88.	243.	364.
5	IN	AVE. FOR STATE		11.63	0.041	32.	88.	243.	364.
5	MI	ANN ARBOR	3	8.01	0.040	22.	58.	156.	232.
5	MI	BAY CITY	3	0.0	0.0	0.	0.	0.	0.
5	MI	DETROIT	3	8.80	0.040	24.	65.	175.	261.
5	MI	FLINT	3	8.61	0.040	23.	63.	172.	256.
5	MI	GRAND RAPIDS	3	10.83	0.041	30.	82.	227.	340.
5	MI	JACKSON	3	0.0	0.0	0.	0.	0.	0.
5	MI	KALAMAZOO	3	10.09	0.040	27.	75.	203.	303.
5	MI	LANSING	3	8.67	0.040	23.	64.	172.	256.
5	MI	MUSKEGON	3	10.46	0.040	29.	79.	215.	322.
5	MI	SAGINAW	3	0.0	0.0	0.	0.	0.	0.
5	MI	OTHER URBAN AREAS		9.04	0.040	25.	67.	181.	270.
5	MI	AVE. FOR STATE		9.04	0.040	25.	67.	181.	270.
5	MN	DULUTH	3	8.42	0.040	23.	62.	169.	251.
5	MN	FARGO METRO	3	4.42	0.039	12.	31.	83.	122.
5	MN	MINNEAPOLIS	3	7.72	0.040	21.	57.	157.	234.
5	MN	ROCHESTER	3	6.72	0.039	18.	48.	128.	190.
5	MN	OTHER URBAN AREAS		7.66	0.040	21.	57.	155.	232.
5	MN	AVE. FOR STATE		7.66	0.040	21.	57.	155.	232.
5	OH	AKRON	3	13.68	0.041	38.	104.	288.	433.
5	OH	CANTON	3	14.25	0.041	39.	109.	303.	456.
5	OH	CINCINNATI	3	8.00	0.039	21.	57.	153.	226.
5	OH	CLEVELAND	3	17.43	0.042	52.	145.	419.	640.
5	OH	COLUMBUS	3	17.04	0.042	48.	137.	390.	592.
5	OH	DAYTON	3	11.91	0.040	33.	90.	247.	371.
5	OH	HAMILTON	3	16.66	0.041	47.	130.	365.	550.
5	OH	LIMA	3	0.0	0.0	0.	0.	0.	0.
5	OH	LORAIN	3	10.50	0.040	29.	78.	212.	316.
5	OH	MANSFIELD	3	9.00	0.039	24.	63.	168.	247.
5	OH	SPRINGFIELD	3	8.34	0.039	22.	60.	158.	234.
5	OH	STEUBENVILLE	3	0.0	0.0	0.	0.	0.	0.
5	OH	TOLEDO	3	9.07	0.040	25.	67.	180.	269.
5	OH	YOUNGSTOWN	3	12.96	0.040	35.	96.	263.	392.
5	OH	OTHER URBAN AREAS		14.21	0.041	40.	112.	315.	477.
5	OH	AVE. FOR STATE		14.21	0.041	40.	112.	315.	477.
5	WI	APPLETON	3	11.40	0.041	32.	88.	246.	371.
5	WI	DULUTH METRO	3	6.68	0.039	18.	48.	127.	188.
5	WI	GREEN BAY	3	6.44	0.039	17.	46.	124.	183.
5	WI	KENOSHA	3	6.42	0.039	17.	45.	119.	175.
5	WI	LA CROSSE	3	7.90	0.040	21.	57.	153.	228.
5	WI	MADISON	3	11.04	0.041	30.	84.	232.	348.
5	WI	MILWAUKEE	3	3.56	0.038	9.	23.	60.	88.
5	WI	OSHKOSH	3	5.80	0.039	15.	41.	109.	161.
5	WI	RACINE	3	8.25	0.040	22.	60.	161.	239.
5	WI	OTHER URBAN AREAS		5.77	0.039	15.	41.	110.	162.
5	WI	AVE. FOR STATE		5.77	0.039	15.	41.	110.	162.
5		AVE. FOR REGION 5		9.10	0.040	25.	69.	189.	283.

TABLE VI-10 ANNUAL CONTROL COSTS - STORM AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	FOR VI-20 COEFS. k	FOR VI-20 COEFS. B	CONTROL COST ($/ACRE) 25%	50%	75%	85%
6	AR	FORT SMITH	4	0.0	0.0	0.	0.	0.	0.
6	AR	LITTLE ROCK	4	13.07	0.040	35.	96.	261.	390.
6	AR	PINE BLUFF	4	11.73	0.040	31.	85.	231.	337.
6	AR	OTHER URBAN AREAS		12.62	0.040	34.	92.	250.	372.
6	AR	AVE. FOR STATE		12.62	0.040	34.	92.	250.	372.
6	LA	BATON ROUGE	4	16.50	0.040	45.	122.	332.	495.
6	LA	LAFAYETTE	4	13.25	0.040	36.	96.	261.	381.
6	LA	LAKE CHARLES	4	13.92	0.040	38.	101.	273.	408.
6	LA	MONROE	4	10.71	0.039	29.	77.	208.	305.
6	LA	NEW ORLEANS	4	33.05	0.043	126.	368.	1077.	1655.
6	LA	SHREVEPORT	4	10.65	0.040	29.	77.	208.	310.
6	LA	OTHER URBAN AREAS		29.87	0.042	86.	249.	717.	1096.
6	LA	AVE. FOR STATE		29.87	0.042	86.	249.	717.	1096.
6	NM	ALBUQUERQUE	2	5.42	0.038	14.	37.	95.	139.
6	NM	OTHER URBAN AREAS		5.42	0.038	14.	37.	95.	139.
6	NM	AVE. FOR STATE		5.42	0.038	14.	37.	95.	139.
6	OK	LAWTON	3	6.59	0.039	17.	46.	123.	182.
6	OK	OKLAHOMA CITY	3	11.19	0.041	31.	85.	236.	354.
6	OK	TULSA	3	12.07	0.040	33.	91.	248.	371.
6	OK	OTHER URBAN AREAS		11.16	0.040	31.	84.	232.	347.
6	OK	AVE. FOR STATE		11.16	0.040	31.	84.	232.	347.
6	TX	ABILENE	3	7.05	0.040	19.	52.	142.	212.
6	TX	AMARILLO	3	6.53	0.040	18.	49.	135.	202.
6	TX	AUSTIN	3	9.23	0.040	25.	68.	183.	272.
6	TX	BEAUMONT	3	18.62	0.040	51.	141.	387.	581.
6	TX	BROWNSVILLE	3	5.73	0.039	15.	40.	108.	159.
6	TX	BRYAN	3	13.38	0.040	37.	101.	278.	417.
6	TX	CORPUS CHRISTI	3	9.80	0.041	27.	75.	206.	310.
6	TX	DALLAS	3	12.58	0.041	35.	96.	265.	398.
6	TX	EL PASO	3	2.76	0.041	8.	21.	58.	88.
6	TX	FORT WORTH	3	10.81	0.041	30.	82.	228.	342.
6	TX	GALVESTON	3	0.0	0.0	0.	0.	0.	0.
6	TX	HARLINGEN	3	4.22	0.038	11.	29.	75.	110.
6	TX	HOUSTON	3	11.79	0.040	31.	85.	227.	337.
6	TX	LAREDO	3	4.43	0.039	12.	32.	85.	126.
6	TX	LUBBOCK	3	4.43	0.040	12.	32.	86.	127.
6	TX	MCALLEN	3	4.47	0.039	12.	32.	84.	124.
6	TX	MIDLAND	3	2.80	0.039	7.	20.	52.	77.
6	TX	ODESSA	3	3.21	0.039	9.	23.	61.	91.
6	TX	PORT ARTHUR	3	12.88	0.039	34.	92.	246.	365.
6	TX	SAN ANGELO	3	3.87	0.039	10.	27.	72.	106.
6	TX	SAN ANTONIO	3	10.79	0.041	30.	83.	232.	349.
6	TX	SHERMAN	3	6.98	0.039	18.	48.	126.	185.
6	TX	TEXARKANA	3	9.55	0.039	25.	67.	178.	262.
6	TX	TEXAS CITY	3	11.88	0.040	32.	86.	231.	344.
6	TX	TYLER	3	11.50	0.040	31.	83.	223.	332.
6	TX	WACO	3	9.79	0.040	26.	72.	196.	292.
6	TX	WICHITA FALL	3	6.39	0.039	17.	45.	120.	178.
6	TX	OTHER URBAN AREAS		10.21	0.040	28.	76.	208.	310.
6	TX	AVE. FOR STATE		10.21	0.040	28.	76.	208.	310.
6		AVE. FOR REGION 6		13.05	0.041	38.	105.	292.	440.

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TABLE VI-10 ANNUAL CONTROL COSTS - STORM AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CITY	EQ. VI-20 COEFS. k	B	CONTROL COST ($/ACRE) 25%	50%	75%	85%
7	IA	CEDAR RAPIDS	3	8.40	0.040	23.	61.	163.	242.
7	IA	DAVENPORT	3	9.61	0.040	26.	71.	191.	285.
7	IA	DES MOINES	3	3.61	0.037	9.	23.	60.	97.
7	IA	DUBUQUE	3	7.10	0.039	19.	50.	133.	197.
7	IA	SIOUX CITY	3	8.30	0.040	23.	63.	173.	257.
7	IA	WATERLOO	3	7.64	0.039	20.	55.	147.	217.
7	IA	OTHER URBAN AREAS		6.97	0.039	19.	50.	134.	198.
7	IA	AVE. FOR STATE		6.97	0.039	19.	50.	134.	198.
7	KS	KANSAS CITY METRO	3	9.53	0.040	26.	70.	189.	282.
7	KS	TOPEKA	3	9.93	0.040	27.	73.	199.	297.
7	KS	WICHITA	3	7.94	0.040	21.	57.	154.	229.
7	KS	OTHER URBAN AREAS		8.67	0.040	23.	63.	170.	254.
7	KS	AVE. FOR STATE		8.67	0.040	23.	63.	170.	254.
7	MO	COLUMBIA	3	11.61	0.040	32.	87.	236.	353.
7	MO	KANSAS CITY	3	3.43	0.039	11.	29.	75.	109.
7	MO	SPRINGFIELD	3	11.96	0.040	32.	88.	239.	357.
7	MO	ST. JOSEPH	3	0.0	0.0	0.	0.	0.	0.
7	MO	ST. LOUIS	3	0.0	0.0	0.	0.	0.	0.
7	MO	OTHER URBAN AREAS		6.94	0.039	18.	49.	130.	193.
7	MO	AVE. FOR STATE		6.94	0.039	18.	49.	130.	193.
7	NE	LINCOLN	3	8.78	0.040	24.	66.	181.	270.
7	NE	OMAHA	3	9.98	0.041	28.	77.	214.	322.
7	NE	OTHER URBAN AREAS		9.24	0.041	25.	70.	194.	290.
7	NE	AVE. FOR STATE		9.24	0.041	25.	70.	194.	290.
7		AVE. FOR REGION 7		7.78	0.040	21.	56.	152.	226.
8	CO	BOULDER	2	12.39	0.038	32.	84.	218.	320.
8	CO	COLORADO SPRINGS	3	6.29	0.039	17.	43.	109.	159.
8	CO	DENVER	2	9.68	0.038	25.	66.	173.	254.
8	CO	PUEBLO	3	4.60	0.037	12.	29.	74.	107.
8	CO	OTHER URBAN AREAS		9.07	0.038	24.	62.	161.	236.
8	CO	AVE. FOR STATE		9.07	0.038	24.	62.	161.	236.
8	MT	BILLINGS	2	6.46	0.038	17.	42.	108.	157.
8	MT	GREAT FALLS	2	6.40	0.037	16.	41.	104.	152.
8	MT	OTHER URBAN AREAS		6.42	0.037	16.	42.	106.	154.
8	MT	AVE. FOR STATE		6.42	0.037	16.	42.	106.	154.
8	ND	FARGO	3	4.93	0.039	13.	35.	94.	140.
8	ND	OTHER URBAN AREAS		4.93	0.039	13.	35.	94.	140.
8	ND	AVE. FOR STATE		4.93	0.039	13.	35.	94.	140.
8	SD	SIOUX FALLS	3	7.36	0.040	20.	54.	148.	221.
8	SD	OTHER URBAN AREAS		7.36	0.040	20.	54.	148.	221.
8	SD	AVE. FOR STATE		7.36	0.040	20.	54.	148.	221.
8	UT	OGDEN	2	10.42	0.038	27.	70.	181.	265.
8	UT	PROVO	2	8.55	0.038	22.	58.	151.	222.
8	UT	SALT LAKE CITY	2	9.40	0.038	24.	63.	164.	241.
8	UT	OTHER URBAN AREAS		9.49	0.038	25.	64.	166.	243.
8	UT	AVE. FOR STATE		9.49	0.038	25.	64.	166.	243.
8	WY	URBAN AREAS	2	7.51	0.038	19.	49.	126.	183.
8	WY	AVE. FOR STATE		7.50	0.038	19.	49.	126.	183.
8		AVE. FOR REGION 8		8.29	0.038	22.	56.	147.	216.

TABLE VI-10 ANNUAL CONTROL COSTS - STORM AREAS

EPA REG	STATE ID	URBANIZED AREA	UFF CTY	FOR VI-20 COEFS. k	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
9	AK	URBAN AREAS	1	14.83	0.040	40.	107.	287.	426.
9	AK	AVE. FOR STATE		14.83	0.040	40.	107.	287.	426.
9	AZ	PHOENIX	2	4.03	0.038	10.	27.	70.	103.
9	AZ	TUCSON	2	5.69	0.038	15.	38.	96.	140.
9	AZ	OTHER URBAN AREAS		4.45	0.038	11.	30.	77.	112.
9	AZ	AVE. FOR STATE		4.45	0.038	11.	30.	77.	112.
9	CA	BAKERSFIELD	1	4.85	0.039	13.	35.	93.	138.
9	CA	FRESNO	1	3.93	0.039	10.	28.	74.	109.
9	CA	LOS ANGELES	1	5.35	0.039	14.	38.	102.	151.
9	CA	MODESTO	1	8.51	0.039	22.	58.	154.	227.
9	CA	OXNARD	1	6.67	0.039	18.	48.	128.	190.
9	CA	SACRAMENTO	1	7.20	0.039	19.	52.	138.	205.
9	CA	SALINAS	1	4.99	0.039	13.	35.	93.	137.
9	CA	SAN BERNARDINO	1	9.15	0.040	25.	66.	178.	265.
9	CA	SAN DIEGO	1	4.77	0.039	13.	34.	91.	136.
9	CA	SAN FRANCISCO	1	10.00	0.039	27.	72.	193.	287.
9	CA	SAN JOSE	1	7.25	0.040	20.	55.	145.	214.
9	CA	SANTA BARBARA	1	6.09	0.039	16.	43.	115.	167.
9	CA	SANTA ROSA	1	8.27	0.039	22.	57.	150.	221.
9	CA	SEASIDE	1	4.27	0.039	11.	29.	77.	114.
9	CA	SIMI VALLEY	1	8.25	0.039	22.	58.	153.	225.
9	CA	STOCKTON	1	4.69	0.039	12.	33.	87.	128.
9	CA	OTHER URBAN AREAS		6.02	0.039	16.	43.	115.	170.
9	CA	AVE. FOR STATE		6.02	0.039	16.	43.	115.	170.
9	HI	HONOLULU	1	10.97	0.039	29.	79.	212.	314.
9	HI	OTHER URBAN AREAS		10.97	0.039	29.	79.	212.	314.
9	HI	AVE. FOR STATE		10.97	0.039	29.	79.	212.	314.
9	NV	LAS VEGAS	2	2.24	0.038	6.	15.	39.	58.
9	NV	RENO	2	3.05	0.037	8.	20.	50.	73.
9	NV	OTHER URBAN AREAS		2.38	0.038	6.	16.	41.	60.
9	NV	AVE. FOR STATE		2.38	0.038	6.	16.	41.	60.
9		AVE. FOR REGION 9		6.06	0.039	16.	43.	115.	171.
10	ID	BOISE	2	4.94	0.037	13.	32.	82.	119.
10	ID	OTHER URBAN AREAS		4.94	0.037	13.	32.	82.	119.
10	ID	AVE. FOR STATE		4.94	0.037	13.	32.	82.	119.
10	OR	EUGENE	1	14.71	0.039	39.	104.	277.	409.
10	OR	PORTLAND	1	18.31	0.039	48.	129.	345.	511.
10	OR	SALEM	1	13.40	0.039	36.	94.	249.	367.
10	OR	OTHER URBAN AREAS		16.65	0.039	44.	119.	317.	469.
10	OR	AVE. FOR STATE		16.65	0.039	44.	119.	317.	469.
10	WA	SEATTLE	1	14.99	0.039	40.	107.	285.	423.
10	WA	SPOKANE	1	0.0	0.0	0.	0.	0.	0.
10	WA	TACOMA	1	16.08	0.039	43.	114.	305.	451.
10	WA	OTHER URBAN AREAS		15.37	0.039	41.	109.	292.	432.
10	WA	AVE. FOR STATE		15.37	0.039	41.	109.	292.	432.
10		AVE. FOR REGION 10		14.12	0.039	38.	100.	266.	394.
		AVERAGE FOR THE U.S.		10.82	0.043	32.	94.	279.	434.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
1	CT	BRIDGEPORT	5	3.26	0.039	9.	23.	61.	91.
1	CT	BRISTOL	5	2.83	0.039	7.	19.	51.	75.
1	CT	DANBURY	5	2.90	0.039	8.	20.	53.	78.
1	CT	HARTFORD	5	3.12	0.039	8.	22.	58.	86.
1	CT	MERIDEN	5	3.06	0.039	8.	21.	58.	85.
1	CT	NEW BRITAIN	5	3.71	0.040	10.	27.	72.	107.
1	CT	NEW HAVEN	5	3.65	0.039	10.	26.	70.	103.
1	CT	NORWALK	5	3.25	0.039	9.	23.	60.	89.
1	CT	STAMFORD	5	3.60	0.039	10.	26.	68.	101.
1	CT	WATERBURY	5	3.53	0.039	9.	25.	66.	98.
1	CT	OTHER URBAN AREAS		3.31	0.039	9.	23.	62.	92.
1	CT	AVE. FOR STATE		3.31	0.039	9.	23.	62.	92.
1	ME	LEWISTON	5	2.74	0.038	7.	19.	49.	71.
1	ME	PORTLAND	5	4.91	0.041	14.	37.	102.	154.
1	ME	OTHER URBAN AREAS		3.68	0.040	10.	27.	72.	107.
1	ME	AVE. FOR STATE		3.68	0.040	10.	27.	72.	107.
1	MA	BOSTON	5	2.82	0.039	7.	19.	51.	75.
1	MA	BROCKTON	5	3.49	0.039	9.	25.	66.	97.
1	MA	FALL RIVER	5	3.45	0.039	9.	24.	65.	96.
1	MA	FITCHBURG	5	3.16	0.039	8.	22.	58.	85.
1	MA	LAWRENCE	5	3.70	0.040	10.	27.	73.	108.
1	MA	LOWELL	5	2.79	0.039	7.	19.	51.	75.
1	MA	NEW BEDFORD	5	3.55	0.040	10.	26.	69.	102.
1	MA	PITTSFIELD	5	2.98	0.039	8.	21.	54.	79.
1	MA	SPRINGFIELD	5	5.32	0.041	15.	41.	112.	168.
1	MA	WORCESTER	5	3.78	0.039	10.	27.	72.	107.
1	MA	OTHER URBAN AREAS		3.32	0.039	9.	24.	63.	93.
1	MA	AVE. FOR STATE		3.32	0.039	9.	24.	63.	93.
1	NH	MANCHESTER	5	3.16	0.039	8.	22.	60.	89.
1	NH	NASHUA	5	4.73	0.040	13.	36.	98.	148.
1	NH	OTHER URBAN AREAS		3.80	0.040	10.	28.	76.	113.
1	NH	AVE. FOR STATE		3.80	0.040	10.	28.	76.	113.
1	RI	PROVIDENCE	5	2.85	0.039	8.	20.	52.	77.
1	RI	OTHER URBAN AREAS		2.85	0.039	8.	20.	52.	77.
1	RI	AVE. FOR STATE		2.85	0.039	8.	20.	52.	77.
1	VT	URBAN AREAS	5	4.11	0.041	11.	31.	87.	130.
1	VT	AVE. FOR STATE		4.11	0.041	11.	31.	87.	130.
1		AVE. FOR REGION 1		3.33	0.039	9.	24.	63.	94.
2	NJ	ATLANTIC CITY	5	2.75	0.039	7.	19.	50.	73.
2	NJ	NEW YORK CITY METRO	5	2.72	0.038	7.	19.	48.	71.
2	NJ	PHILADELPHIA METRO	5	2.06	0.037	5.	13.	34.	50.
2	NJ	TRENTON	5	3.65	0.040	10.	26.	71.	105.
2	NJ	VINELAND	5	3.22	0.039	9.	23.	60.	88.
2	NJ	AVE. FOR STATE		2.74	0.038	7.	19.	49.	72.
2	NY	ALBANY	5	2.65	0.039	7.	18.	49.	72.
2	NY	BINGHAMPTON	5	3.13	0.040	8.	23.	61.	90.
2	NY	BUFFALO	5	2.81	0.039	7.	20.	53.	78.
2	NY	NEW YORK CITY	5	0.0	0.0	0.	0.	0.	0.
2	NY	ROCHESTER	5	2.05	0.038	5.	14.	37.	54.
2	NY	SYRACUSE	5	3.04	0.039	8.	22.	59.	87.
2	NY	UTICA	5	3.53	0.039	9.	25.	67.	99.
2	NY	OTHER URBAN AREAS		2.69	0.039	7.	19.	50.	74.
2	NY	AVE. FOR STATE		2.69	0.039	7.	19.	50.	74.
2		AVE. FOR REGION 2		2.73	0.039	7.	19.	49.	72.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	FOR VI-20 COEFS. k	FOR VI-20 COEFS. β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
3	DE	WILMINGTON	5	3.60	0.039	10.	26.	68.	101.
3	DE	OTHER URBAN AREAS		3.60	0.039	10.	26.	68.	101.
3	DE	AVE. FOR STATE		3.60	0.039	10.	26.	68.	101.
3	DC	WASHINGTON,D.C.	5	0.0	0.0	0.	0.	0.	0.
3	DC	AVE. FOR STATE		0.0	0.0	0.	0.	0.	0.
3	MD	BALTIMORE	5	3.37	0.039	9.	24.	64.	94.
3	MD	WASHINGTON DC METRO	5	3.02	0.039	8.	21.	56.	83.
3	MD	OTHER URBAN AREAS		3.25	0.039	9.	23.	61.	90.
3	MD	AVE. FOR STATE		3.25	0.039	9.	23.	61.	90.
3	PA	ALLENTOWN	5	3.26	0.039	9.	23.	61.	89.
3	PA	ALTOONA	5	3.81	0.040	10.	28.	74.	110.
3	PA	ERIE	5	3.28	0.040	9.	24.	66.	95.
3	PA	HARRISBURG	5	2.65	0.039	7.	18.	48.	71.
3	PA	JOHNSTOWN	5	4.50	0.040	12.	33.	91.	134.
3	PA	LANCASTER	5	3.78	0.040	10.	27.	74.	110.
3	PA	PHILADELPHIA	5	3.50	0.039	9.	25.	67.	99.
3	PA	PITTSBURGH	5	1.95	0.035	5.	13.	33.	48.
3	PA	READING	5	3.64	0.040	10.	26.	71.	105.
3	PA	SCRANTON	5	3.52	0.040	9.	26.	69.	103.
3	PA	WILKES-BARRE	5	3.11	0.038	8.	22.	59.	88.
3	PA	YORK	5	3.70	0.040	10.	26.	73.	109.
3	PA	OTHER URBAN AREAS		2.71	0.039	7.	19.	50.	73.
3	PA	AVE. FOR STATE		2.71	0.039	7.	19.	50.	73.
3	VA	LYNCHBURG	5	0.0	0.0	0.	0.	0.	0.
3	VA	NEWPORT NEWS	5	3.21	0.039	8.	22.	59.	87.
3	VA	NORFOLK	5	2.90	0.038	8.	20.	52.	78.
3	VA	PETERSBURG	5	2.77	0.038	7.	19.	50.	73.
3	VA	RICHMOND	5	3.39	0.039	9.	24.	64.	95.
3	VA	ROANOKE	5	3.65	0.040	10.	26.	71.	105.
3	VA	WASHINGTON DC METRO	5	0.0	0.0	0.	0.	0.	0.
3	VA	OTHER URBAN AREAS		3.13	0.039	8.	22.	57.	85.
3	VA	AVE. FOR STATE		3.13	0.039	8.	22.	57.	85.
3	WV	CHARLESTON	5	3.46	0.039	9.	24.	65.	96.
3	WV	HUNTINGTON	5	0.0	0.0	0.	0.	0.	0.
3	WV	STEUBENVILLE METRO	5	0.0	0.0	0.	0.	0.	0.
3	WV	WHEELING	5	3.89	0.040	11.	29.	78.	117.
3	WV	OTHER URBAN AREAS		3.57	0.039	10.	26.	68.	101.
3	WV	AVE. FOR STATE		3.57	0.039	10.	26.	68.	101.
3		AVE. FOR REGION 3		2.94	0.039	8.	21.	55.	81.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
4	AL	BIRMINGHAM	4	5.34	0.037	14.	35.	89.	129.
4	AL	GADSDEN	4	4.49	0.037	11.	28.	71.	103.
4	AL	HUNTSVILLE	4	4.07	0.037	10.	26.	64.	93.
4	AL	MOBILE	4	5.88	0.037	15.	37.	95.	137.
4	AL	MONTGOMERY	4	5.12	0.037	13.	33.	84.	122.
4	AL	TUSCALOOSA	4	6.81	0.036	17.	44.	118.	167.
4	AL	OTHER URBAN AREAS		5.33	0.037	14.	34.	87.	127.
4	AL	AVE. FOR STATE		5.33	0.037	14.	34.	87.	127.
4	FL	FT. LAUDERDALE	4	5.28	0.037	13.	34.	85.	123.
4	FL	GAINESVILLE	4	5.32	0.038	14.	36.	92.	135.
4	FL	JACKSONVILLE	4	4.26	0.037	11.	27.	67.	98.
4	FL	MIAMI	4	5.68	0.037	14.	37.	93.	135.
4	FL	ORLANDO	4	3.98	0.037	10.	25.	63.	90.
4	FL	PENSACOLA	4	5.71	0.037	14.	37.	93.	134.
4	FL	ST. PETERSBURG	4	4.56	0.037	11.	29.	73.	105.
4	FL	TALLAHASSEE	4	5.00	0.037	13.	32.	81.	117.
4	FL	TAMPA	4	4.03	0.037	10.	25.	63.	92.
4	FL	WEST PALM BEACH	4	5.72	0.037	15.	37.	93.	135.
4	FL	OTHER URBAN AREAS		4.87	0.037	12.	31.	78.	113.
4	FL	AVE. FOR STATE		4.87	0.037	12.	31.	78.	113.
4	GA	ALBANY	4	0.0	0.0	0.	0.	0.	0.
4	GA	ATLANTA	4	4.90	0.038	13.	32.	82.	119.
4	GA	AUGUSTA	4	5.97	0.039	16.	41.	108.	158.
4	GA	COLUMBUS	4	5.19	0.038	13.	34.	87.	127.
4	GA	MACON	4	4.17	0.037	11.	27.	68.	99.
4	GA	SAVANNAH	4	4.69	0.037	12.	30.	76.	110.
4	GA	OTHER URBAN AREAS		4.95	0.038	13.	32.	83.	121.
4	GA	AVE. FOR STATE		4.95	0.038	13.	32.	83.	121.
4	KY	HUNTINGTON METRO	5	3.56	0.040	10.	26.	70.	104.
4	KY	LEXINGTON	5	3.77	0.040	10.	27.	73.	108.
4	KY	LOUISVILLE	5	2.89	0.039	8.	20.	53.	78.
4	KY	OWENSBORO	5	3.84	0.040	10.	28.	75.	111.
4	KY	OTHER URBAN AREAS		3.04	0.039	8.	21.	57.	84.
4	KY	AVE. FOR STATE		3.04	0.039	8.	21.	57.	84.
4	MS	BILOXI	4	6.18	0.038	16.	40.	104.	151.
4	MS	JACKSON	4	4.91	0.037	12.	32.	81.	117.
4	MS	OTHER URBAN AREAS		5.49	0.037	14.	36.	91.	133.
4	MS	AVE. FOR STATE		5.49	0.037	14.	36.	91.	133.
4	NC	ASHEVILLE	4	3.73	0.037	9.	23.	59.	85.
4	NC	CHARLOTTE	4	4.54	0.038	12.	30.	77.	112.
4	NC	DURHAM	4	5.27	0.038	14.	35.	91.	133.
4	NC	FAYETTEVILLE	4	4.83	0.038	13.	32.	82.	120.
4	NC	GREENSBORO	4	3.78	0.037	10.	24.	61.	89.
4	NC	HIGHPOINT	4	5.76	0.038	15.	39.	100.	146.
4	NC	RALEIGH	4	4.64	0.037	12.	30.	77.	112.
4	NC	WILMINGTON	4	3.98	0.037	10.	25.	63.	90.
4	NC	WINSTON-SALEM	4	4.94	0.038	13.	32.	83.	120.
4	NC	OTHER URBAN AREAS		4.69	0.038	12.	31.	78.	114.
4	NC	AVE. FOR STATE		4.69	0.038	12.	31.	78.	114.
4	SC	CHARLESTON	4	5.06	0.038	13.	33.	85.	124.
4	SC	COLUMBIA	4	4.95	0.038	13.	32.	83.	121.
4	SC	GREENVILLE	4	4.82	0.038	12.	32.	81.	117.
4	SC	OTHER URBAN AREAS		4.96	0.038	13.	32.	83.	121.
4	SC	AVE. FOR STATE		4.96	0.038	13.	32.	83.	121.
4	TN	CHATTANOOGA	4	5.26	0.037	13.	34.	87.	126.
4	TN	KNOXVILLE	4	4.77	0.038	12.	31.	80.	116.
4	TN	MEMPHIS	4	4.00	0.037	10.	26.	64.	92.
4	TN	NASHVILLE	4	3.78	0.037	9.	24.	59.	86.
4	TN	OTHER URBAN AREAS		4.22	0.037	11.	27.	68.	99.
4	TN	AVE. FOR STATE		4.22	0.037	11.	27.	68.	99.
4		AVE. FOR REGION 4		4.74	0.037	12.	31.	78.	114.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. α	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
5	IL	AURORA	3	2.98	0.037	7.	19.	47.	67.
5	IL	BLOOMINGTON	3	3.38	0.037	8.	21.	53.	77.
5	IL	CHAMPAIGN	3	3.85	0.037	10.	25.	[illegible]	90.
5	IL	CHICAGO	3	3.05	0.037	8.	19.	48.	70.
5	IL	DAVENPORT METRO	3	4.56	0.038	12.	30.	78.	113.
5	IL	DECATUR	3	6.19	0.039	16.	42.	110.	162.
5	IL	JOLIET	3	[illegible]	0.038	[illegible]	[illegible]	[illegible]	[illegible]
5	IL	PEORIA	3	5.53	0.038	14.	37.	97.	143.
5	IL	ROCKFORD	3	3.17	0.037	8.	20.	50.	73.
5	IL	SPRINGFIELD	3	3.67	0.037	10.	25.	63.	92.
5	IL	OTHER URBAN AREAS		3.35	0.037	8.	21.	54.	78.
5	IL	AVE. FOR STATF		3.35	0.037	8.	21.	54.	78.
5	IN	ANDERSON	3	0.0	0.0	0.	0.	0.	0.
5	IN	CHICAGO METRO	3	2.93	0.037	7.	18.	46.	67.
5	IN	EVANSVILLE	3	0.0	0.0	0.	0.	0.	0.
5	IN	FORT WAYNE	3	2.99	0.037	7.	19.	47.	69.
5	IN	INDIANAPOLIS	3	3.18	0.036	8.	20.	49.	70.
5	IN	LAFAYETTE	3	0.0	0.0	0.	0.	0.	0.
5	IN	MUNCIE	3	5.06	0.038	13.	33.	85.	[illegible]
5	IN	SOUTH BEND	3	5.72	0.038	15.	39.	101.	148.
5	IN	TERRA HAUTE	3	5.37	0.038	14.	37.	95.	139.
5	IN	OTHER URBAN AREAS		3.42	0.037	9.	22.	55.	79.
5	IN	AVE. FOR STATE		3.42	0.037	9.	22.	55.	79.
5	MI	ANN ARBOR	3	3.43	0.037	9.	22.	56.	82.
5	MI	BAY CITY	3	4.85	0.039	13.	33.	87.	128.
5	MI	DETROIT	3	2.86	0.037	7.	18.	45.	65.
5	MI	FLINT	3	3.09	0.037	8.	20.	50.	73.
5	MI	GRAND RAPIDS	3	2.72	0.037	7.	17.	43.	62.
5	MI	JACKSON	3	4.65	0.038	12.	31.	80.	116.
5	MI	KALAMAZOO	3	3.24	0.037	8.	21.	52.	76.
5	MI	LANSING	3	3.23	0.037	8.	21.	52.	76.
5	MI	MUSKEGON	3	2.86	0.037	7.	18.	45.	65.
5	MI	SAGINAW	3	5.12	0.039	13.	35.	93.	137.
5	MI	OTHER URBAN AREAS		3.03	0.037	8.	19.	49.	70.
5	MI	AVE. FOR STATE		3.03	0.037	8.	19.	49.	70.
5	MN	DULUTH	3	2.65	0.037	7.	17.	42.	60.
5	MN	FARGO METRO	3	2.67	0.038	7.	18.	45.	66.
5	MN	MINNEAPOLIS	3	2.18	0.037	5.	14.	34.	49.
5	MN	ROCHESTER	3	3.44	0.037	9.	22.	57.	83.
5	MN	OTHER URBAN AREAS		2.23	0.037	6.	14.	35.	51.
5	MN	AVE. FOR STATE		2.23	0.037	6.	14.	35.	51.
5	OH	AKRON	3	3.36	0.037	8.	21.	53.	76.
5	OH	CANTON	3	3.35	0.037	8.	21.	53.	78.
5	OH	CINCINNATI	3	4.06	0.037	10.	26.	65.	95.
5	OH	CLEVELAND	3	2.35	0.036	6.	14.	34.	48.
5	OH	COLUMBUS	3	2.91	0.038	7.	18.	45.	65.
5	OH	DAYTON	3	3.25	0.037	8.	20.	51.	74.
5	OH	HAMILTON	3	3.22	0.036	8.	20.	50.	71.
5	OH	LIMA	3	0.0	0.0	0.	0.	0.	0.
5	OH	LORAIN	3	3.14	0.037	8.	20.	49.	71.
5	OH	MANSFIELD	3	[illegible]	0.038	13.	35.	90.	[illegible]
5	OH	SPRINGFIELD	3	5.19	0.038	13.	34.	88.	128.
5	OH	STEUBENVILLE	3	0.0	0.0	0.	0.	0.	0.
5	OH	TOLEDO	3	3.14	0.037	8.	20.	50.	73.
5	OH	YOUNGSTOWN	3	4.15	0.037	10.	26.	66.	96.
5	OH	OTHER URBAN AREAS		3.08	0.037	8.	19.	48.	70.
5	OH	AVE. FOR STATF		3.08	0.037	8.	19.	48.	70.
5	WI	APPLETON	3	2.56	0.037	6.	16.	40.	57.
5	WI	DULUTH METRO	3	2.69	0.037	7.	17.	43.	62.
5	WI	GREEN BAY	3	3.08	0.037	8.	20.	51.	74.
5	WI	KENOSHA	3	0.0	0.0	0.	0.	0.	0.
5	WI	LA CROSSE	3	3.47	0.037	9.	22.	57.	83.
5	WI	MADISON	3	2.75	0.037	7.	17.	43.	62.
5	WI	MILWAUKEE	3	3.36	0.036	9.	22.	56.	82.
5	WI	OSHKOSH	3	0.0	0.0	0.	0.	0.	0.
5	WI	RACINE	3	3.35	0.037	9.	21.	53.	78.
5	WI	OTHER URBAN AREAS		3.21	0.037	8.	21.	53.	77.
5	WI	AVE. FOR STATE.		3.21	0.037	8.	21.	53.	77.
5		AVE. FOR REGION 5		3.08	0.037	8.	20.	49.	71.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	DEF CTY	EQN VI-20 COEFS. k	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
6	AR	FORT SMITH	4	5.52	0.038	14.	37.	96.	141.
6	AR	LITTLE ROCK	4	5.89	0.038	15.	39.	101.	148.
6	AR	PINE BLUFF	4	5.82	0.038	15.	38.	99.	144.
6	AR	OTHER URBAN AREAS		5.80	0.038	15.	39.	100.	146.
6	AR	AVE. FOR STATE		5.80	0.038	15.	39.	100.	146.
6	LA	BATON ROUGE	4	5.84	0.037	15.	38.	96.	140.
6	LA	LAFAYETTE	4	6.62	0.038	17.	44.	112.	163.
6	LA	LAKE CHARLES	4	6.18	0.038	16.	40.	104.	151.
6	LA	MONROE	4	6.10	0.038	16.	41.	105.	154.
6	LA	NEW ORLEANS	4	0.0	0.0	0.	0.	0.	0.
6	LA	SHREVEPORT	4	4.82	0.038	12.	32.	81.	118.
6	LA	OTHER URBAN AREAS		5.64	0.038	14.	37.	95.	138.
6	LA	AVE. FOR STATE		5.64	0.038	14.	37.	95.	138.
6	NM	ALBUQUERQUE	2	1.45	0.036	4.	9.	21.	30.
6	NM	OTHER URBAN AREAS		1.45	0.036	4.	9.	21.	30.
6	NM	AVE. FOR STATE		1.45	0.036	4.	9.	21.	30.
6	OK	LAWTON	3	3.94	0.038	10.	26.	67.	97.
6	OK	OKLAHOMA CITY	3	2.49	0.036	6.	15.	38.	55.
6	OK	TULSA	3	3.32	0.037	9.	21.	52.	75.
6	OK	OTHER URBAN AREAS		2.91	0.037	7.	18.	46.	66.
6	OK	AVE. FOR STATE		2.91	0.037	7.	18.	46.	66.
6	TX	ABILENE	3	1.97	0.037	5.	12.	31.	44.
6	TX	AMARILLO	3	1.74	0.037	4.	11.	27.	40.
6	TX	AUSTIN	3	3.45	0.037	9.	22.	56.	81.
6	TX	BEAUMONT	3	4.45	0.036	11.	28.	69.	99.
6	TX	BROWNSVILLE	3	3.46	0.038	9.	23.	59.	85.
6	TX	BRYAN	3	3.14	0.036	8.	20.	49.	71.
6	TX	CORPUS CHRISTI	3	2.25	0.036	6.	14.	35.	50.
6	TX	DALLAS	3	2.66	0.036	7.	16.	41.	58.
6	TX	EL PASO	3	0.61	0.037	2.	4.	10.	14.
6	TX	FORT WORTH	3	2.51	0.036	6.	15.	40.	57.
6	TX	GALVESTON	3	4.74	0.037	12.	31.	79.	114.
6	TX	HARLINGEN	3	3.53	0.038	9.	23.	60.	88.
6	TX	HOUSTON	3	5.22	0.037	13.	34.	86.	125.
6	TX	LAREDO	3	2.21	0.037	6.	14.	37.	54.
6	TX	LUBBOCK	3	1.98	0.037	5.	13.	33.	47.
6	TX	MCALLEN	3	2.78	0.038	7.	18.	47.	69.
6	TX	MIDLAND	3	1.80	0.038	5.	12.	31.	45.
6	TX	ODESSA	3	1.60	0.037	4.	10.	27.	39.
6	TX	PORT ARTHUR	3	6.29	0.037	16.	41.	104.	151.
6	TX	SAN ANGELO	3	2.48	0.038	6.	16.	42.	62.
6	TX	SAN ANTONIO	3	2.46	0.037	6.	16.	39.	56.
6	TX	SHERMAN	3	5.31	0.036	14.	35.	91.	132.
6	TX	TEXARKANA	3	6.17	0.038	16.	41.	105.	153.
6	TX	TEXAS CITY	3	4.05	0.037	10.	25.	64.	92.
6	TX	TYLER	3	5.11	0.037	13.	33.	84.	122.
6	TX	WACO	3	2.71	0.037	7.	17.	43.	61.
6	TX	WICHITA FALL	3	3.78	0.038	10.	25.	64.	94.
6	TX	OTHER URBAN AREAS		3.22	0.037	8.	20.	52.	75.
6	TX	AVE. FOR STATE		3.22	0.037	8.	20.	52.	75.
6		AVE. FOR REGION 6		3.47	0.037	9.	22.	56.	82.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	DEF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. B	CONTROL COST ($/ACRE) 25%	50%	75%	85%
7	IA	CEDAR RAPIDS	3	3.69	0.037	9.	24.	61.	88.
7	IA	DAVENPORT	3	3.15	0.037	8.	20.	50.	72.
7	IA	DES MOINES	3	2.82	0.037	7.	18.	46.	64.
7	IA	DUBUQUE	3	4.26	0.038	11.	28.	72.	105.
7	IA	SIOUX CITY	3	2.07	0.037	5.	13.	32.	46.
7	IA	WATERLOO	3	3.67	0.037	9.	24.	61.	88.
7	IA	OTHER URBAN AREAS		3.13	0.037	8.	20.	50.	73.
7	IA	AVE. FOR STATE		3.13	0.037	8.	20.	50.	73.
7	KS	KANSAS CITY METRO	3	3.56	0.037	9.	23.	58.	84.
7	KS	TOPEKA	3	3.42	0.037	9.	22.	55.	80.
7	KS	WICHITA	3	3.45	0.037	9.	22.	57.	82.
7	KS	OTHER URBAN AREAS		3.48	0.037	9.	22.	57.	82.
7	KS	AVE. FOR STATE		3.48	0.037	9.	22.	57.	82.
7	MO	COLUMBIA	3	3.15	0.037	8.	20.	49.	71.
7	MO	KANSAS CITY	3	3.90	0.037	10.	25.	64.	94.
7	MO	SPRINGFIELD	3	4.01	0.037	10.	25.	64.	93.
7	MO	ST.JOSEPH	3	0.0	0.0	0.	0.	0.	0.
7	MO	ST.LOUIS	3	7.48	0.039	20.	53.	138.	204.
7	MO	OTHER URBAN AREAS		5.64	0.038	15.	38.	100.	147.
7	MO	AVE. FOR STATE		5.64	0.038	15.	38.	100.	147.
7	NE	LINCOLN	3	2.56	0.037	6.	16.	41.	59.
7	NE	OMAHA	3	2.26	0.037	6.	14.	35.	51.
7	NE	OTHER URBAN AREAS		2.33	0.037	6.	15.	37.	53.
7	NE	AVE. FOR STATE		2.33	0.037	6.	15.	37.	53.
7		AVE. FOR REGION 7		4.12	0.038	11.	27.	70.	103.
8	CO	BOULDER	2	3.44	0.036	8.	21.	50.	72.
8	CO	COLORADO SPRINGS	2	2.58	0.036	6.	16.	38.	55.
8	CO	DENVER	2	2.22	0.036	5.	13.	32.	45.
8	CO	PUEBLO	2	2.40	0.036	6.	14.	35.	51.
8	CO	OTHER URBAN AREAS		2.33	0.036	6.	14.	34.	48.
8	CO	AVE. FOR STATE		2.33	0.036	6.	14.	34.	48.
8	MT	BILLINGS	2	2.61	0.036	6.	16.	38.	55.
8	MT	GREAT FALLS	2	3.34	0.036	8.	21.	51.	73.
8	MT	OTHER URBAN AREAS		2.90	0.036	7.	18.	43.	62.
8	MT	AVE. FOR STATE		2.90	0.036	7.	18.	43.	62.
8	ND	FARGO	3	2.53	0.038	6.	17.	42.	62.
8	ND	OTHER URBAN AREAS		2.53	0.038	6.	17.	42.	62.
8	ND	AVE. FOR STATE		2.53	0.038	6.	17.	42.	62.
8	SD	SIOUX FALLS	3	2.63	0.037	7.	17.	43.	62.
8	SD	OTHER URBAN AREAS		2.63	0.037	7.	17.	43.	62.
8	SD	AVE. FOR STATE		2.63	0.037	7.	17.	43.	62.
8	UT	OGDEN	2	2.89	0.036	7.	17.	42.	60.
8	UT	PROVO	2	1.85	0.035	4.	11.	26.	37.
8	UT	SALT LAKE CITY	2	2.45	0.036	6.	14.	35.	50.
8	UT	OTHER URBAN AREAS		2.44	0.036	6.	14.	35.	50.
8	UT	AVE. FOR STATE		2.44	0.036	6.	14.	35.	50.
8	WY	URBAN AREAS	2	3.04	0.036	7.	18.	45.	64.
8	WY	AVE. FOR STATE		3.04	0.036	7.	18.	45.	64.
8		AVE. FOR REGION 8		2.49	0.036	6.	15.	37.	53.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	b	CONTROL COST ($/ACRE) 25%	50%	75%	85%
9	AK	URBAN AREAS	1	2.98	0.037	8.	19.	48.	69.
9	AK	AVE. FOR STATE		2.98	0.037	8.	19.	48.	69.
9	AZ	PHOENIX	2	0.96	0.035	2.	[illegible]	[illegible]	[illegible]
9	AZ	TUCSON	2	[illegible]	0.036	[illegible]	[illegible]	[illegible]	[illegible]
9	AZ	OTHER URBAN AREAS		1.23	0.036	3.	7.	18.	25.
9	AZ	AVE. FOR STATE		1.25	0.036	3.	7.	18.	25.
9	CA	BAKERSFIELD	1	1.17	0.037	3.	8.	19.	[illegible]
9	CA	FRESNO	1	[illegible]	0.037	3.	9.	[illegible]	[illegible]
9	CA	LOS ANGELES	1	[illegible]	0.037	4.	10.	[illegible]	[illegible]
9	CA	MODESTO	1	[illegible]	[illegible]	4.	[illegible]	[illegible]	[illegible]
9	CA	OXNARD	1	[illegible]	[illegible]	4.	[illegible]	[illegible]	[illegible]
9	CA	SACRAMENTO	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	SALINAS	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	SAN BERNARDINO	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	SAN DIEGO	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	SAN FRANCISCO	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	SAN JOSE	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	SANTA BARBARA	1	[illegible]	[illegible]	[illegible]	16.	40.	[illegible]
9	CA	SANTA ROSA	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	SEASIDE	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	SIMI VALLEY	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	CA	STOCKTON	1	[illegible]	[illegible]	5.	12.	[illegible]	45.
9	CA	OTHER URBAN AREAS		1.69	0.037	4.	11.	27.	40.
9	CA	AVE. FOR STATE		1.69	0.037	4.	11.	27.	40.
9	HI	HONOLULU	1	2.60	0.037	7.	17.	42.	61.
9	HI	OTHER URBAN AREAS		2.60	0.037	7.	17.	42.	61.
9	HI	AVE. FOR STATE		2.60	0.037	7.	17.	42.	61.
9	NV	LAS VEGAS	2	0.50	0.035	1.	3.	7.	10.
9	NV	RENO	2	1.33	0.036	3.	7.	18.	26.
9	NV	OTHER URBAN AREAS		0.70	0.036	2.	4.	10.	14.
9	NV	AVE. FOR STATE		0.70	0.036	2.	4.	10.	14.
9		AVE. FOR REGION 9		1.66	0.037	4.	11.	27.	38.
10	ID	BOISE	2	2.55	0.036	6.	16.	38.	55.
10	ID	OTHER URBAN AREAS		2.55	0.036	6.	16.	38.	55.
10	ID	AVE. FOR STATE		2.55	0.036	6.	16.	38.	55.
10	OR	EUGENE	1	4.74	0.037	12.	31.	78.	[illegible]
10	OR	PORTLAND	1	4.59	0.037	12.	[illegible]	[illegible]	[illegible]
10	OR	SALEM	1	5.66	[illegible]	14.	37.	[illegible]	[illegible]
10	OR	OTHER URBAN AREAS		4.72	0.037	12.	30.	77.	112.
10	OR	AVE. FOR STATE		4.72	0.037	12.	30.	77.	112.
10	WA	SEATTLE	1	4.07	0.037	10.	26.	66.	96.
10	WA	SPOKANE	1	[illegible]	[illegible]	10.	[illegible]	[illegible]	[illegible]
10	WA	TACOMA	1	[illegible]	[illegible]	12.	[illegible]	[illegible]	[illegible]
10	WA	OTHER URBAN AREAS		4.17	0.037	11.	27.	68.	99.
10	WA	AVE. FOR STATE		4.17	0.037	11.	27.	68.	99.
10		AVE. FOR REGION 10		4.21	0.037	11.	27.	69.	100.
		AVERAGE FOR THE U.S.		3.31	0.038	8.	22.	56.	81.

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Because of this definition, the number of overflows may increase with an increase in treatment rate as shown in Figure VI-12, Effect of Storage and Treatment Capacity on Number of Overflow Events. If the treatment rate is high enough to deplete storage after the first overflow, then the event is over. When storage is utilized later a new event starts, and any overflow occurring in this event is considered separate from the first overflow. Thus, the number of overflow events was increased from one to two events, even though the treatment rate was increased.

The number of overflow events appears to provide a more meaningful parameter if the event is defined differently than the definition used by STORM. The overflows shown in case 2 in Figure VI-12, should be considered as a single event since they occur so closely together. The event would then be redefined to be a separate overflow event if there was a specified length of time between it and the overflows preceding and following the event.

Determination of a National Precipitation Event Definition

A methodology is presented by which separate precipitation events may be defined on a national scale. Several valid, but totally different, alternate approaches will be briefly discussed and evaluated with regard to each one's usefulness in deriving a national event definition. The main portion will be devoted to the derivation of a precipitation event definition for the five test cities. Each city has precipitation records which are representative of the climatologic region in which it is located. From the results for each region a national precipitation event definition will be formulated for the contiguous United States. Given an event definition the relationship between the number of overflow events and volume of runoff controlled will be presented.

Meteorologic studies are one approach which may provide a useful insight into the definition of a national precipitation event. Since the atmospheric mechanisms for the cooling that creates saturation are of three types -- cyclonic, orographic, and convective -- an event definition could be based upon storm origination (e.g., all precipitation resulting from one frontal movement would be considered a single event even if the front became stationary with extended periods of zero precipitation). This would dictate an event duration range of from an extended period (i.e., 12 to 72 hours) for a cyclonic storm to a short period (i.e., seldom more than one hour) for a convective storm.[17] This causal concept would not be applicable for even a local precipitation event definition since localities are subjected to both cyclonic and convective storms. Even a twofold definition -- one each for cyclonic and convective origination -- is inappropriate as cyclonic storms may be divided into frontal and nonfrontal varieties. Overshadowing the possibly solvable problem of regionalizing cyclonic and convective precipitation events is the problem of identifying all future

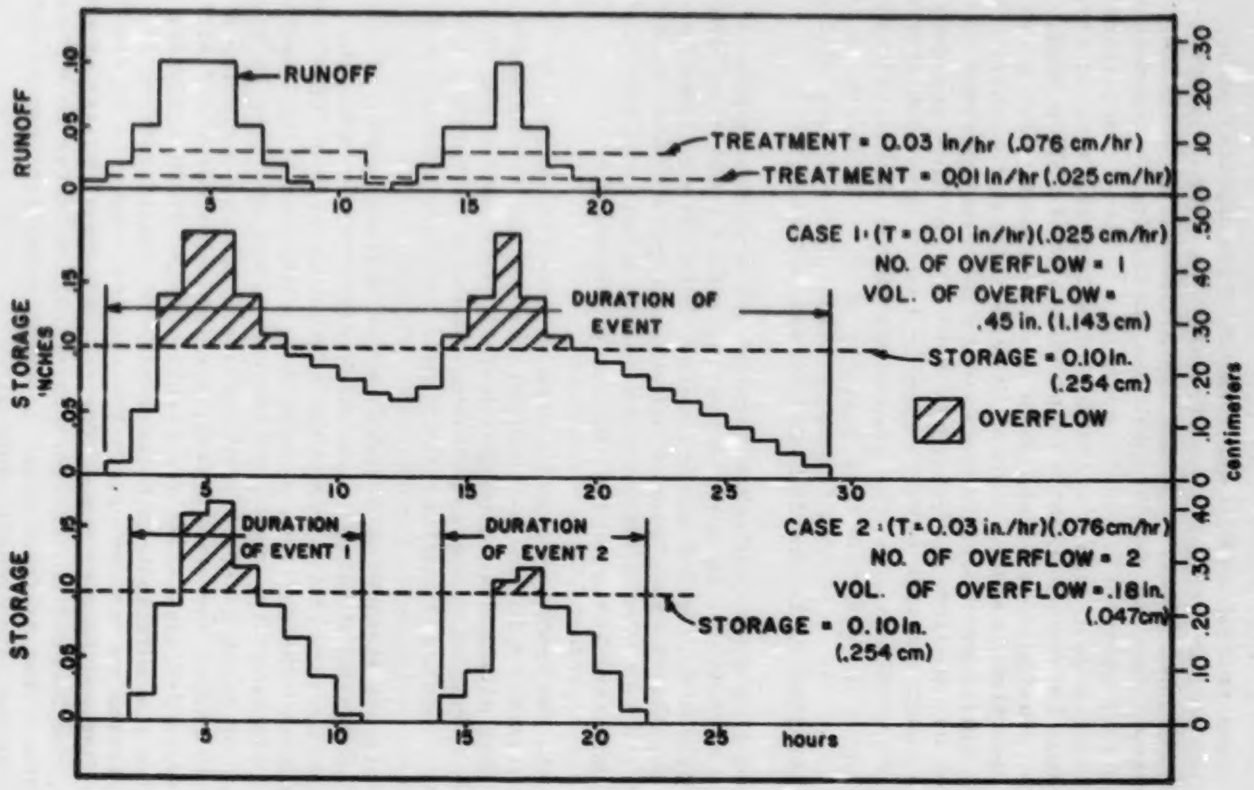


Figure VI-12. Effect of Storage and Treatment Capacity on Number of Overflow Events.

storm types in order to determine the number of events. These difficulties make the envisioned national precipitation event definition an unattainable entity via this approach.

A second approach to this event definition is a statistical one. The examination of the probability distribution of storm characteristics is accomplished first by separating a time-series of point rainfall observations into events which are statistically independent by use of the rank correlation coefficient.[18,19] Then, combination with a significance test allows selection of a limiting time interval (i.e., a minimum interevent time) between nonzero rainfall pulses, such that the hypothesis of independence may be rejected with a chosen level of assurance for nonzero pulses which are closer together. This time between independent precipitation events has been observed to follow closely the Weibull distribution.[18,19] Use of this approach would be applicable for a specific region at best. Extensive studies would be required to determine the parameters of the Weibull distribution. Furthermore, comprehensive validity of this technique is open to question as it was developed through studies of convective storms only in northeastern North America and Tucson, Arizona.[18,19]

A final approach could be one which established a minimum number of consecutive dry (i.e., no measurable precipitation) hours that must precede and follow individual storm events. This rather elementary concept is probably the best current approach to providing a useable event definition that can readily be applied on a national scale. This dry hour or zero precipitation approach is presented next.

In general, the following procedures were utilized to develop the event definition for each of the study cities. A one year precipitation record that approximates the average rainfall distribution was obtained for each city. Precipitation events were tabulated by varying the number of zero rainfall hours necessary to divide two separate events.

A "minimum interevent time" is defined as the minimum number of consecutive zero precipitation hours which must occur between two separate storm events. By varying the "minimum interevent time" the number of separate storm events generated is tabulated. The results are shown in Figure VI-13, Effect of Minimum Interevent Time on the Annual Number of Storm Events. Based on a qualitative analysis, a value of 12 hours is chosen for the national precipitation event definition. Using this event definition and the results of the STORM analysis, one can derive the relationship between percent runoff control and number of overflow events per year. The results, shown in Figure VI-14, Relationship Between Percent Runoff Control and Annual Number of Overflow Events, can be used to transform the final estimates to a base of events per year. The no-first-flush isoquant parameters can be used to estimate the level of runoff control.

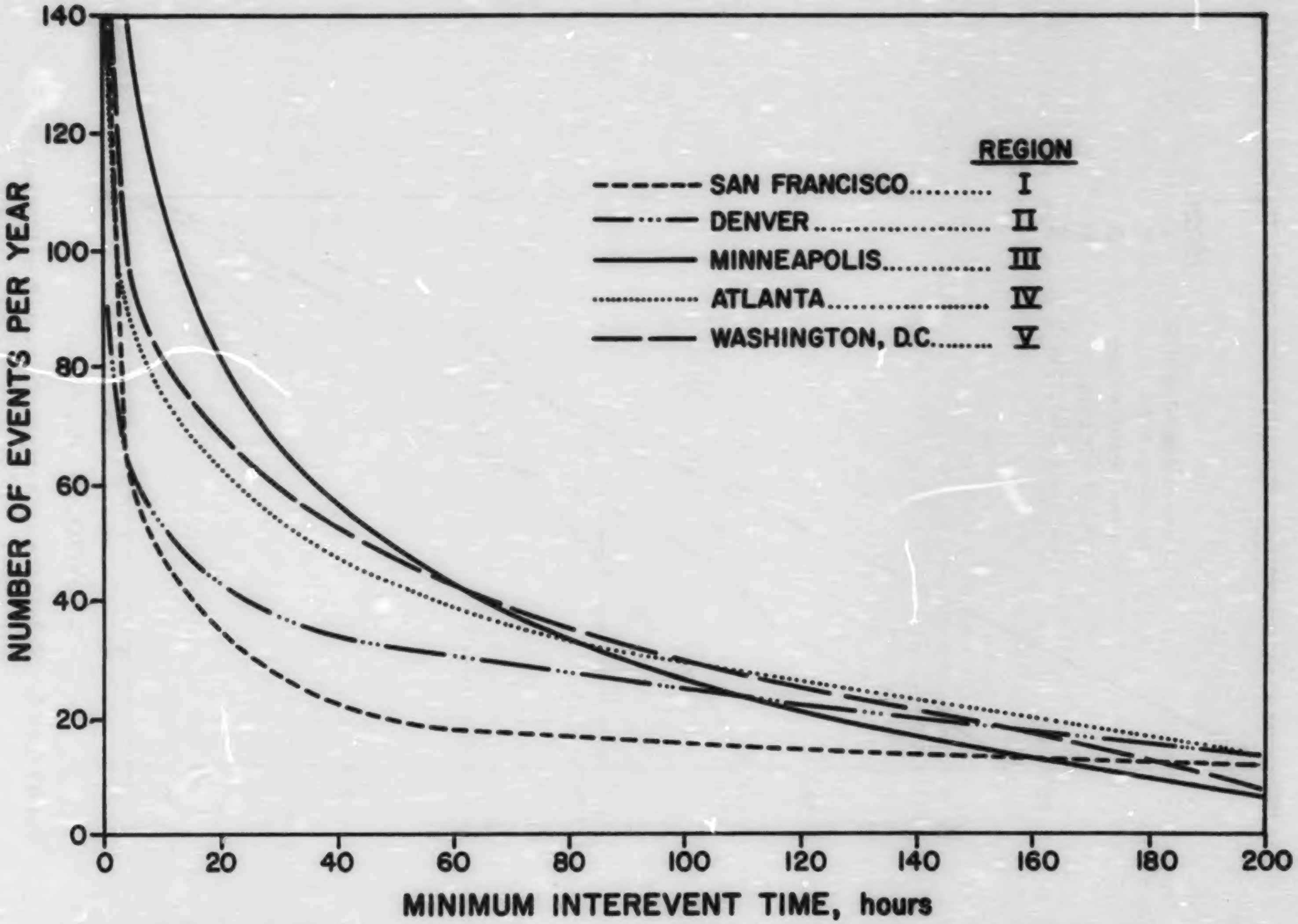


Figure VI-13. Effect of Minimum Interevent Time on the Annual Number of Storm Events

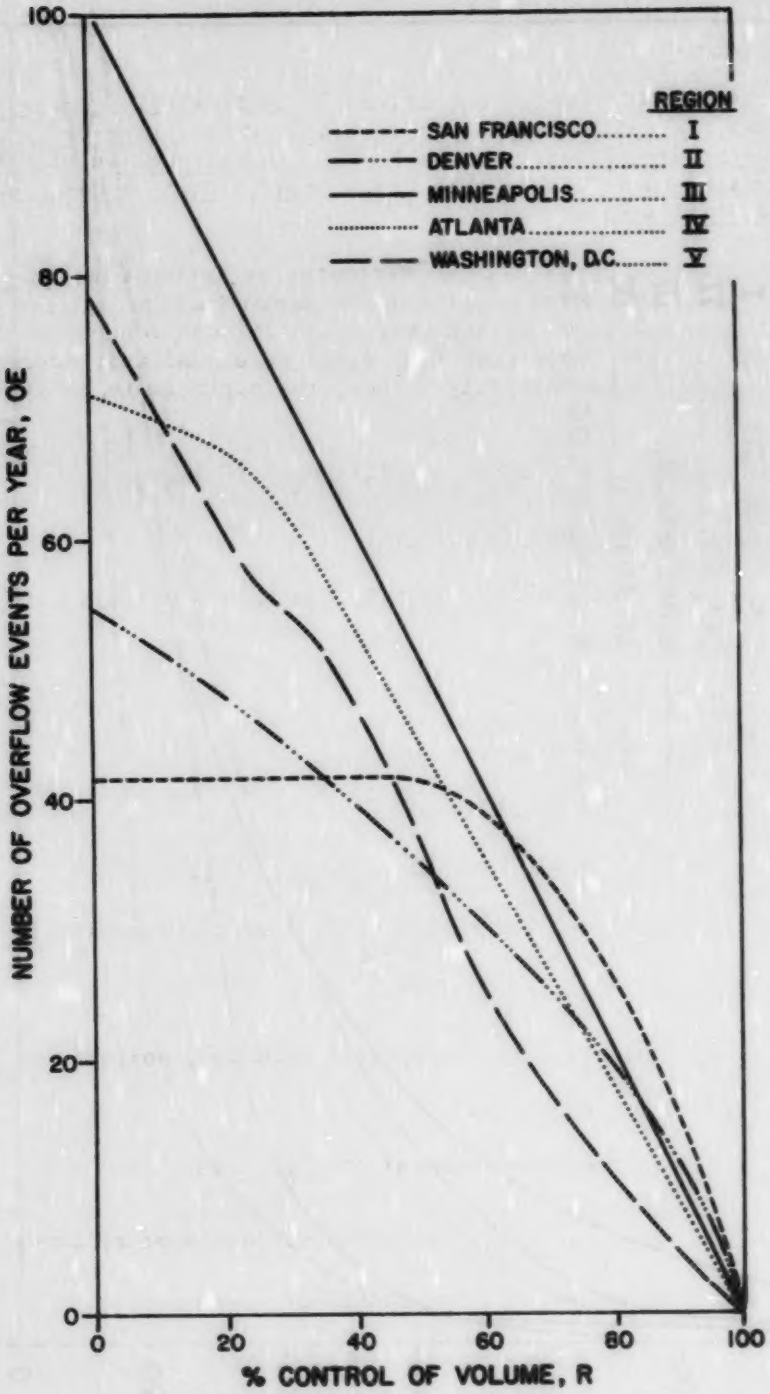


Figure VI-14. Relationship Between Percent Runoff Control and Annual Number of Overflow Events

OVERALL COST ASSESSMENT

Overall Results

General results thus far are summarized in Table VI-12, General Information, Table VI-13, Land Use by Type of Use, Table VI-14, Land Use and Population by Type of Sewerage System, Table VI-15, Quantity and Quality of Sewage and Stormwater Runoff, and Table VI-16, Annual Control Costs per Unit of Developed Urban Area.

The only remaining problem is to estimate the nation-wide costs for 25, 50, 75, and 85 percent control. As a first approximation, assume that an overall 25 percent control level is achieved by 25 percent control on the combined (A_1), storm (A_2) and unsewered (A_3) areas at annual unit costs ($ per acre) of C_1, C_2, and C_3, respectively. Thus, the approximate total annual costs, TAC, are

$$(TAC)_{25} = (C_1)_{25}A_1 + (C_2)_{25}A_2 + (C_3)_{25}A_3. \qquad \text{(VI-21)}$$

From Tables VI-14 and VI-16, we obtain

$$(TAC)_{25} = 47(2.248 \times 10^6) + 32(5.987) \times 10^6) + 8(7.393 \times 10^6)$$
$$= \$356.4 \times 10^6/hr.$$

Likewise,

$$(TAC)_{50} = \$1,065 \times 10^6 \qquad \text{(VI-22)}$$
$$(TAC)_{75} = \$3,210 \times 10^6$$
$$(TAC)_{85} = \$5,029 \times 10^6.$$

Recall that the cost of wet-weather control using secondary facilities is

$$Z^*_s = ke^{\beta R_1} \qquad \text{(VI-24)}$$

where Z^*_s = annual cost for optimal solution, dollars per acre,

k, β = constants, and

R_1 = percent BOD removal ($0 \leq R_1 \leq 85$).

The cost of wet weather control in terms of pounds of pollutant removed, w, is

$$Z^*_s = ke^{\beta(100)(\frac{w}{M})} \qquad \text{(VI-25)}$$

where w = pollutant removal, lbs/acre-yr, and

M = pollutants available, lbs/acre-yr.

Table VI-12. GENERAL INFORMATION

Total Urbanized Area = 29.037×10^6 ac (11.751×10^6 ha)

Total Population = 149.366×10^6 persons

Average Population Density = 5.14 persons/acre (12.7 persons/ha)

Average Precipitation = 33.4 inches/year (84.8 cm/year)

Table VI-13. LAND USE BY TYPE OF USE

Use	10^6 Acres (ha)
Undeveloped	13.409 (5.426)
Residential	9.120 (3.691)
Commercial	1.337 (0.541)
Industrial	2.324 (0.941)
Other	2.847 (1.152)
Total	29.037 (11.751)

Table VI-14. LAND USE AND POPULATION BY TYPE OF SEWERAGE SYSTEM

	10^6 Acres (ha)	10^6 Persons	Developed Population Density Persons/ Acre (ha)
Undeveloped	13.409 (5.426)	0	0
Combined	2.248 (0.910)	37.606	16.7 (41.3)
Storm	5.987 (2.423)	77.853	13.0 (32.1)
Unsewered	7.393 (2.992)	33.906	4.6 (11.4)
	29.037 (11.751)	149.366	9.6 (23.7)

Table VI-15. QUANTITY AND QUALITY OF SEWAGE AND STORMWATER RUNOFF

	Flow: in./yr (cm/yr)		Quality: Annual Pounds of BOD/acre (kg/ha)	
Sewerage System	Sanitary Sewage[a]	Storm Runoff[b]	Sanitary Sewage[c]	Storm Runoff[d]
Combined	22.5 (57.2)	16.5 (41.9)	1039 (1167)	136.6 (153.0)
Storm	17.5 (44.5)	14.8 (37.6)	807 (907)	30.5 (35.3)
Unsewered	6.2 (15.7)	10.8 (27.4)	285 (320)	25.9 (26.5)
Weighted Average	12.8 (32.5)	13.4 (34.0)	594 (667)	43.6 (49.0)

[a] Table IV-4 [b] Table IV-3 [c] Table V-11 [d] Table V-10

Table VI-16. ANNUAL CONTROL COSTS PER UNIT OF DEVELOPED URBAN AREA: $/ACRE ($/HA)

	Level of Control, % of Total				Coefficients	
Type of Sewerage System	25	50	75	85	k	β
Combined[a]	47 (116)	151 (373)	501 (1238)	815 (2013)	14.05	0.048
Storm[b]	32 (79.1)	94 (232)	279 (689)	434 (1072)	10.82	0.043
Unsewered[c]	8 (19.8)	22 (54.4)	56 (138)	81 (200)	3.31	0.038

[a] Table VI-9 [b] Table VI-10 [c] Table VI-11

The marginal cost of BOD removal is

$$\frac{dZ_s^*}{dw} = \frac{100\ \beta\ k}{M}\ e^{\frac{100\beta\ w}{M}} \qquad \text{(VI-26)}$$

Given these convex cost functions, the optimal mix of control of storm runoff from combined, storm, and unsewered areas is found by equating marginal costs. Using equation VI-26 with the subscript (1) denoting combined, (2) denoting storm, and (3) denoting unsewered, yields

$$\begin{aligned} \frac{100\ \beta_1 k_1}{M_1}\ e^{\frac{100\ \beta_1 w_1}{M_1}} &= \frac{100\ \beta_2 k_2}{M_2}\ e^{\frac{100\ \beta_2 w_2}{M_2}} \\ &= \frac{100\ \beta_3 k_3}{M_3}\ e^{\frac{100\ \beta_3 w_3}{M_3}} \end{aligned} \qquad \text{(VI-27)}$$

If marginal costs for, say, 50% BOD removal are compared, one obtains

$$\begin{aligned} MC_1 &= \frac{100(0.048)(14.05)}{136.6}\ e^{100(0.048)(0.5)} \\ &= \$5.44/\text{lb BOD } (\$11.99/\text{kg BOD}) \end{aligned} \qquad \text{(VI-28)}$$

$$\begin{aligned} MC_2 &= \frac{100(0.043)(10.82)}{30.5}\ e^{100(0.043)(0.5)} \\ &= \$13.10/\text{lb BOD } (\$28.85/\text{kg BOD}) \end{aligned} \qquad \text{(VI-29)}$$

$$\begin{aligned} MC_3 &= \frac{100(0.038)(3.31)}{25.9}\ e^{100(0.038)(0.5)} \\ &= \$3.25/\text{lb BOD } (\$7.15/\text{kg BOD}) \end{aligned} \qquad \text{(VI-30)}$$

This result indicates that, to achieve 50 percent control, storm sewered areas should be controlled less intensively due to their relatively high marginal costs and unsewered areas should be controlled more intensively because of their relatively low marginal cost.

The correct solution can be found by solving for w_1 and w_3 as functions of w_2, i.e.,

$$w_1 = a_{12} + b_{12} w_2 \qquad 0 \le w_1 \le .85\ M_1 \qquad \text{(VI-31)}$$

$$w_3 = a_{32} + b_{32}w_2 \quad 0 \leq w_3 \leq .85\ M_3 \qquad \text{(VI-32)}$$

where $a_{12} = \frac{M_1}{100\ \beta_1} \ln [(\frac{\beta_2}{\beta_1})(\frac{k_2}{k_1})(\frac{M_1}{M_2})]$

$a_{32} = \frac{M_3}{100\ \beta_3} \ln [(\frac{\beta_2}{\beta_3})(\frac{k_2}{k_3})(\frac{M_3}{M_2})]$

$b_{12} = (\frac{\beta_2}{\beta_1})(\frac{M_1}{M_2})$

$b_{32} = (\frac{\beta_2}{\beta_3})(\frac{M_3}{M_2})$

M_1, M_2, M_3, β_1, β_2, β_3, k_1, k_2, k_3, w_1, w_2, w_3 are as defined earlier.

The total wet-weather pollution load, WP (pounds/year), is

$$WP = \sum_{i=1}^{3} M_i A_i \qquad \text{(VI-33)}$$

where M_i = annual pounds per acre from i^{th} area, and

A_i = area of i^{th} area, acres.

Let ρ denote the proportion of WP that one wishes to control. Then, the optimal removal, w_i^*, for a given ρ is found by substituting equations VI-31 and VI-32 into VI-33, or

$$\rho(WP) = w_1A_1 + w_2A_2 + w_3A_3 \qquad \text{(VI-34)}$$

$$\rho(WP) = (a_{12} + b_{12}w_2)A_1 + w_2A_2 + (a_{32} + b_{32}w_2)A_3 \qquad \text{(VI-35)}$$

$$w_2^* = \frac{\rho(WP) - a_{12}A_1 - a_{32}A_3}{b_{12}A_1 + A_2 + b_{32}A_3} \qquad \text{(VI-36)}$$

where w_i^* = optimal annual pounds per acre removed from the i^{th} source area.

Knowing w_2^*, one can find w_1^* and w_3^* by substituting into equations VI-31 and VI-32.

The optimal percent control of the ith source for control level, ρ, in terms of w_i^* is

$$(R_i^*)_\rho = \frac{100(w_i^*)_\rho}{M_i} \qquad 0 \le (R_i^*)_\rho \le 85 \qquad \text{(VI-37)}$$

The optimal percent control for 25, 50, 75, and 85 percent is shown in Table VI-17, Optimal Percent Control For Specified Overall Percent Control. Knowing (R_i), one can find the cost per acre by simply substituting into equation VI-24, i.e.,

$$Z_s^* = ke^{\beta R_i} \qquad \text{(VI-38)}$$

to obtain the optimal annual cost per acre as shown in Table VI-18, Optimal Annual Cost per Acre for Specified Percent Control. Thus, the optimal annual control costs are shown in Table VI-19, Optimal Annual Control Costs. These costs are approximately 17 percent less than the approximate values reported earlier for 25, 50, and 75 percent control, i.e. equations VI-21 and VI-22.

Tertiary Treatment vs Wet-Weather-Treatment

The optimal mix of tertiary treatment and wet-weather control can be found by equating the marginal cost of tertiary treatment with the marginal cost of wet-weather pollution control. The estimated total annual incremental cost of a tertiary treatment plant is:[20]

$$C_{tert} = 87{,}000\, D^{0.787} \qquad \text{(VI-39)}$$

where C_{tert} = total annual incremental cost of tertiary treatment plant, dollars per year, and

D = plant size, mgd.

Assume a 25 mgd plant. Then, C_{tert} = \$1,096,000 per year. The plant is assumed to increase the BOD removal from 85 percent to 95 percent or about 0.017 pounds (7.71 g) per capita-day or 1,550,000 pounds (704,000 kg) per year for the city of 250,000 people. Thus, the unit cost of tertiary treatment, c_{tert}, is \$0.71 per pound (\$1.55 per kg) of BOD removed.

Equating the marginal cost of wet weather control to the unit cost of tertiary treatment yields

$$c_{tert} = \frac{100\beta\, k}{M} e^{\frac{100\beta\, w}{M}} \qquad \text{(VI-40)}$$

TABLE VI-17 OPTIMAL PERCENT CONTROL FOR SPECIFIED OVERALL PERCENT CONTROL

EPA REG	STATE ID	OPTIMAL PERCENT CONTROL 25% COMB	STORM	UNSEW	50% COMB	STORM	UNSEW	75% COMB	STORM	UNSEW	85% COMB	STORM	UNSEW
1	CT	31.0	3.9	28.6	54.6	29.1	56.1	78.1	54.2	83.5	85.0	85.0	85.0
1	ME	27.9	0.0	3.0	52.8	0.0	28.7	77.7	0.0	54.5	85.0	0.0	85.0
1	MA	34.6	0.0	26.1	60.5	18.4	54.4	84.9	42.2	81.2	85.0	85.0	85.0
1	NH	28.3	0.0	3.7	53.2	0.0	29.5	78.1	0.0	55.3	85.0	0.0	85.0
1	RI	26.5	7.0	32.1	50.5	32.1	59.4	75.1	57.8	85.0	85.0	85.0	85.0
1	VT	32.0	0.0	0.8	56.9	0.0	26.0	81.8	0.0	51.2	85.0	0.0	85.0
2	NJ	29.0	4.0	42.7	48.9	28.1	70.2	77.9	63.0	85.0	85.0	85.0	85.0
2	NY	27.3	2.6	58.8	51.9	27.4	85.0	78.5	54.3	85.0	85.0	85.0	85.0
3	DE	36.7	3.5	27.5	61.1	27.9	54.0	85.0	52.7	81.0	85.0	85.0	85.0
3	DC	25.8	27.9	0.0	48.9	52.5	0.0	72.0	82.8	0.0	85.0	85.0	0.0
3	MD	0.0	16.1	46.2	0.0	40.4	73.0	0.0	70.8	85.0	0.0	85.0	85.0
3	PA	32.2	8.9	42.4	55.7	33.5	70.3	83.3	62.4	85.0	85.0	85.0	85.0
3	VA	44.6	3.3	36.5	69.2	27.8	63.5	85.0	61.5	85.0	85.0	85.0	85.0
3	WV	27.2	0.0	6.5	52.3	9.6	43.1	77.2	33.9	59.3	85.0	85.0	85.0
4	AL	0.0	10.4	36.3	0.0	34.9	62.1	0.0	62.1	85.0	0.0	85.0	85.0
4	FL	40.9	9.9	43.0	64.7	33.9	69.2	85.0	66.6	85.0	85.0	85.0	85.0
4	GA	37.8	0.9	21.4	62.3	25.4	47.4	85.0	51.6	75.1	85.0	85.0	85.0
4	KY	44.0	6.6	37.3	68.4	30.6	64.0	85.0	62.5	85.0	85.0	85.0	85.0
4	MS	0.0	12.1	35.3	0.0	36.2	61.0	0.0	62.5	85.0	0.0	85.0	85.0
4	NC	0.0	11.7	34.7	0.0	35.8	60.4	0.0	61.3	85.0	0.0	85.0	85.0
4	SC	0.0	13.1	33.9	0.0	37.3	59.5	0.0	61.6	85.0	0.0	85.0	85.0
4	TN	39.0	1.2	31.9	63.3	25.2	58.1	85.0	50.9	85.0	85.0	85.0	85.0
5	IL	22.0	24.7	40.8	45.7	52.6	70.4	71.9	83.5	85.0	85.0	85.0	85.0
5	IN	28.4	0.0	19.3	53.7	18.6	46.8	78.3	39.1	73.6	85.0	85.0	85.0
5	MI	28.2	0.8	27.7	52.6	25.9	54.8	77.0	51.0	82.0	85.0	85.0	85.0
5	MN	34.4	0.0	29.5	58.8	23.6	56.2	83.1	47.8	82.7	85.0	85.0	85.0
5	OH	30.6	0.0	28.3	56.3	16.8	56.9	80.7	40.9	84.0	85.0	85.0	85.0
5	WI	18.6	20.4	35.8	39.7	46.7	63.5	63.7	76.6	85.0	85.0	85.0	85.0

TABLE VI-17 OPTIMAL PERCENT CONTROL FOR SPECIFIED OVERALL PERCENT CONTROL

EPA RGN	STATE ID	OPTIMAL PERCENT CONTROL 25% COMB	STORM	UNSEW	50% COMB	STORM	UNSEW	75% COMB	STORM	UNSEW	85% COMB	STORM	UNSEW
6	AR	55.0	1.4	19.3	80.1	25.5	44.6	85.0	56.8	77.5	85.0	85.0	85.0
6	LA	0.0	13.6	54.3	0.0	37.7	81.6	0.0	71.1	85.0	0.0	85.0	85.0
6	NM	0.0	7.4	41.6	0.0	31.5	67.5	0.0	64.4	85.0	0.0	85.0	85.0
6	OK	0.0	5.8	39.5	0.0	29.4	65.5	0.0	61.7	85.0	0.0	85.0	85.0
6	TX	25.7	10.2	39.1	44.9	34.3	65.3	69.2	64.9	85.0	85.0	85.0	85.0
7	IA	12.7	15.7	36.5	40.9	41.4	63.9	53.7	73.5	85.0	85.0	85.0	85.0
7	KS	38.2	4.2	27.1	62.6	20.7	53.3	85.0	54.4	80.8	85.0	85.0	85.0
7	MO	31.4	0.0	4.2	56.3	24.1	29.8	81.2	49.2	55.4	85.0	85.0	85.0
7	NE	27.7	1.3	28.7	52.5	20.3	56.3	76.8	44.8	83.4	85.0	85.0	85.0
8	CO	24.6	9.5	44.7	45.4	34.0	70.9	73.8	67.3	85.0	85.0	85.0	85.0
8	MT	0.0	16.7	36.7	0.0	41.3	62.3	0.0	67.9	85.0	0.0	85.0	85.0
8	ND	51.4	15.5	32.4	76.1	40.1	58.3	85.0	67.6	85.0	85.0	85.0	85.0
8	SD	44.8	9.5	35.5	68.9	33.6	61.4	85.0	61.8	85.0	85.0	85.0	85.0
8	UT	0.0	6.3	41.9	0.0	30.9	67.8	0.0	64.3	85.0	0.0	85.0	85.0
8	WY	0.0	13.0	36.5	0.0	37.4	42.1	0.0	64.6	85.0	0.0	85.0	85.0
9	AK	36.1	0.3	39.0	60.2	24.4	64.9	85.0	56.4	85.0	85.0	85.0	85.0
9	AZ	0.0	3.6	41.6	0.0	32.8	67.4	0.0	65.1	85.0	0.0	85.0	85.0
9	CA	19.7	13.4	47.6	41.7	38.6	74.4	69.9	71.1	85.0	85.0	85.0	85.0
9	HI	0.0	10.4	46.3	0.0	35.0	71.9	0.0	68.2	85.0	0.0	85.0	85.0
9	NV	30.2	2.5	35.6	54.1	27.0	61.7	80.1	53.5	85.0	85.0	85.0	85.0
10	ID	0.0	16.4	33.7	0.0	41.0	59.1	0.0	65.6	84.5	0.0	85.0	85.0
10	OR	31.9	0.3	27.7	57.0	22.6	54.1	81.6	47.2	80.1	85.0	85.0	85.0
10	WA	32.2	0.6	23.8	57.8	19.7	50.7	82.5	44.3	76.6	85.0	85.0	85.0

TABLE VI-18 OPTIMAL ANNUAL COST PER ACRE FOR SPECIFIED PERCENT CONTROL

		OPTIMAL ANNUAL COST PER ACRE											
		25%			50%			75%			85%		
EPA REG	STATE ID	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW
1	CT	43.	17.	10.	127.	32.	30.	371.	95.	87.	510.	352.	92.
1	ME	18.	0.	4.	50.	0.	11.	139.	0.	32.	187.	0.	107.
1	MA	41.	0.	9.	124.	31.	28.	355.	90.	80.	356.	592.	93.
1	NH	19.	6.	4.	53.	0.	12.	147.	0.	34.	196.	0.	113.
1	RI	46.	11.	10.	133.	32.	29.	396.	96.	77.	614.	297.	77.
1	VT	18.	5.	4.	49.	0.	12.	137.	0.	33.	157.	0.	130.
2	NJ	55.	16.	14.	157.	44.	41.	727.	215.	72.	1068.	565.	72.
2	NY	116.	25.	23.	450.	39.	74.	1955.	425.	74.	2797.	2271.	74.
3	DE	48.	12.	11.	135.	33.	36.	374.	94.	87.	374.	374.	101.
3	DC	125.	32.	0.	460.	118.	6.	1696.	434.	0.	3546.	481.	0.
3	MD	0.	22.	20.	0.	53.	56.	0.	233.	90.	0.	830.	90.
3	PA	62.	17.	14.	193.	40.	41.	456.	175.	73.	711.	474.	73.
3	VA	55.	13.	13.	155.	42.	37.	305.	171.	85.	305.	473.	85.
3	WV	19.	6.	5.	53.	14.	13.	149.	41.	37.	206.	360.	101.
4	AL	0.	25.	21.	0.	52.	54.	0.	178.	127.	0.	445.	127.
4	FL	101.	27.	30.	366.	72.	65.	610.	271.	113.	610.	570.	113.
4	GA	47.	12.	11.	125.	32.	29.	310.	90.	83.	310.	340.	121.
4	KY	61.	15.	13.	172.	41.	37.	350.	164.	84.	350.	435.	84.
4	MS	0.	22.	21.	0.	58.	54.	0.	164.	135.	0.	403.	133.
4	NC	0.	19.	17.	0.	49.	45.	0.	135.	114.	0.	348.	114.
4	SC	0.	19.	18.	0.	50.	46.	0.	131.	121.	0.	332.	121.
4	TN	61.	15.	14.	162.	41.	36.	387.	115.	99.	387.	858.	99.
5	IL	66.	15.	15.	198.	46.	46.	667.	154.	78.	1225.	164.	78.
5	IN	31.	0.	7.	87.	21.	19.	233.	57.	52.	305.	364.	79.
5	MI	38.	9.	8.	105.	25.	23.	285.	69.	63.	396.	270.	78.
5	MN	39.	0.	7.	80.	20.	18.	212.	52.	47.	229.	232.	51.
5	OH	39.	0.	9.	113.	29.	25.	306.	77.	67.	365.	477.	78.
5	WI	50.	13.	12.	142.	36.	34.	459.	117.	77.	1385.	162.	77.

TABLE VI-18 OPTIMAL ANNUAL COST PER ACRE FOR SPECIFIED PERCENT CONTROL

		OPTIMAL ANNUAL COST PER ACRE											
		25%			50%			75%			85%		
EPA RFG	STATE ID	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW	COMB	STORM	UNSEW
6	AR	85.	15.	13.	117.	45.	31.	141.	121.	110.	141.	372.	146.
6	LA	0.	53.	44.	0.	118.	121.	0.	609.	138.	0.	1096.	138.
6	NM	0.	7.	5.	0.	18.	16.	0.	63.	30.	0.	139.	30.
6	OK	0.	14.	12.	0.	37.	32.	0.	136.	66.	0.	347.	66.
6	TX	82.	15.	14.	217.	81.	36.	743.	139.	75.	1665.	310.	75.
7	IA	49.	15.	12.	134.	36.	33.	472.	126.	73.	2688.	198.	73.
7	KS	43.	10.	10.	118.	27.	25.	287.	75.	70.	287.	254.	82.
7	MO	28.	6.	7.	76.	18.	19.	202.	47.	47.	235.	193.	147.
7	NE	31.	6.	7.	45.	21.	14.	239.	57.	50.	322.	290.	53.
8	CO	45.	13.	11.	113.	33.	29.	412.	119.	48.	684.	236.	48.
8	MT	0.	12.	11.	0.	30.	27.	0.	81.	62.	0.	154.	62.
8	ND	37.	9.	7.	98.	24.	23.	140.	70.	62.	140.	140.	62.
8	SD	40.	11.	10.	116.	29.	26.	221.	87.	62.	221.	221.	62.
8	UT	0.	12.	11.	0.	31.	27.	0.	110.	50.	0.	243.	50.
8	WY	0.	12.	11.	0.	31.	29.	0.	85.	64.	0.	183.	64.
9	AK	62.	15.	13.	160.	39.	33.	426.	138.	69.	426.	426.	69.
9	AZ	0.	6.	5.	0.	15.	14.	0.	53.	25.	0.	112.	25.
9	CA	63.	13.	10.	169.	27.	27.	607.	99.	40.	1201.	170.	40.
9	HI	0.	17.	14.	0.	43.	38.	0.	162.	61.	0.	314.	61.
9	NV	17.	5.	2.	43.	7.	6.	115.	18.	14.	142.	60.	14.
10	ID	0.	9.	8.	0.	23.	22.	0.	57.	54.	0.	119.	55.
10	OR	65.	0.	13.	169.	40.	35.	445.	106.	93.	509.	469.	112.
10	WA	40.	0.	10.	108.	33.	28.	283.	88.	73.	314.	432.	99.

TABLE VI-19 OPTIMAL ANNUAL CONTROL COSTS

EPA REG	STATE ID	OPTIMAL ANNUAL CONTROL COST (MILLIONS OF DOLLARS) 25%	50%	75%	85%
1	CT	3.6	13.5	39.5	68.6
1	ME	0.9	2.3	7.0	11.1
1	MA	6.7	25.4	72.8	157.1
1	NH	0.7	1.7	5.0	8.7
1	RI	1.7	5.3	14.6	24.2
1	VT	0.2	0.5	1.9	2.5
TL REG 1		14.0	49.0	140.8	272.5
2	NJ	12.5	35.8	115.2	229.8
2	NY	37.9	144.9	593.3	1245.2
TL REG 2		50.4	180.7	708.5	1475.1
3	DE	0.7	2.1	5.9	11.0
3	DC	2.8	8.8	32.6	57.2
3	MD	6.1	17.8	53.2	90.7
3	PA	17.8	51.5	159.1	293.2
3	VA	5.2	14.9	45.0	91.9
3	WV	1.2	3.8	9.6	15.5
TL REG 3		33.1	98.2	305.4	559.3
4	AL	5.7	14.8	38.9	66.9
4	FL	16.5	43.1	121.5	214.6
4	GA	6.1	16.2	45.1	75.6
4	KY	3.0	8.5	25.2	49.0
4	MS	2.7	6.9	18.2	30.5
4	NC	5.2	13.6	35.7	59.9
4	SC	2.9	7.5	19.6	32.1
4	TN	5.4	14.3	37.9	71.7
TL REG 4		47.2	124.9	340.0	600.3
5	IL	29.5	85.5	263.6	437.0
5	IN	6.6	19.4	52.1	86.9
5	MI	12.9	33.2	96.1	155.8
5	MN	2.6	8.8	23.3	42.4
5	OH	12.6	42.8	115.8	224.7
5	WI	5.5	15.6	40.5	78.1
TL REG 5		69.7	207.3	595.5	1024.9

TABLE VI-19 OPTIMAL ANNUAL CONTROL COSTS

EPA REG	STATE ID	OPTIMAL ANNUAL CONTROL COST (MILLIONS OF DOLLARS) 25%	50%	75%	95%
6	AR	1.9	5.0	14.3	24.9
6	LA	9.9	27.7	88.7	152.2
6	NM	0.6	1.5	3.9	6.8
6	OK	3.0	7.9	21.5	40.1
6	TX	16.5	43.5	118.3	206.9
TL	REG 6	32.0	85.5	246.7	430.7
7	IA	3.0	8.1	23.1	48.3
7	KS	2.5	6.5	17.3	30.2
7	MO	5.9	16.2	43.2	71.5
7	NE	1.3	4.0	10.7	19.1
TL	REG 7	12.6	34.8	94.2	168.1
8	CO	2.5	6.2	17.0	28.9
8	MT	0.5	1.3	3.2	5.0
8	ND	0.3	0.8	2.1	3.4
8	SD	0.4	1.0	2.7	4.7
8	UT	1.2	3.1	8.1	14.3
8	WY	0.3	0.7	1.8	2.9
TL	REG 8	5.2	13.1	35.0	59.2
9	AK	0.3	0.8	2.1	4.0
9	AZ	1.0	2.6	6.7	11.5
9	CA	21.9	59.2	172.3	287.6
9	HI	1.1	2.8	7.9	13.5
9	NV	0.2	0.4	1.1	1.9
TL	REG 9	24.5	65.8	190.1	318.5
10	ID	0.4	1.0	2.5	3.9
10	OR	3.2	10.4	27.5	47.8
10	WA	4.6	14.9	39.2	69.2
TL	REG 10	8.2	26.4	69.2	120.9
TL	U.S.	296.7	885.7	2725.4	5029.0

or

$$w^* = \frac{M}{100\beta} \ln \left[\frac{c_{tert}(M)}{100\beta\ (k)}\right] \qquad \text{(VI-41)}$$

where w^* = optimal pounds of wet-weather pollution to control prior to using tertiary treatment, pounds/acre-yr.

The optimal percent control in terms of R_1 is

$$R_1^* = \max \left(\frac{1}{\beta} \ln \left[\frac{c_{tert}(\overline{M})}{100\beta\ (k)}\right], 0\right). \qquad \text{(VI-42)}$$

The overall average BOD loading per acre, $\overline{M}$ (pounds/acre-yr), is

$$\overline{M} = \frac{WP}{A_{tot}} = \frac{6.81 \times 10^6}{15.63 \times 10^6} \qquad \text{(VI-43)}$$

$$\overline{M} = 43.6 \text{ lb BOD/ac-yr } (34.0 \text{ kg BOD/ha-yr})$$

where A_{tot} = total developed area in US, acres.

The overall cost function for the US is $Z = 5.37e^{0.047R_1}$. Thus,

$$R_1^* = \max \left[\frac{1}{0.047} \ln \frac{0.71(43.6)}{100(0.047)(5.37)}; 0\right] \qquad \text{(VI-44)}$$

$$R_1^* = 4.3\%.$$

Thus, for these assumed conditions, approximately 4 percent of the wet-weather pollution should be controlled prior to initiating tertiary treatment. While these results are for one specific set of assumptions, they do suggest that it is highly desirable to do this tradeoff analysis before committing a community to tertiary treatment.

Potential Savings Due to Multipurpose Planning

The cost of wet-weather quality control can be reduced by integrating this purpose with dry-weather sewage treatment plants and/or storage facilities for stormwater quantity control. Therefore, it has been suggested that flow equalization be considered as an alternative to conventional design.[21] The storage volume needed for dry-weather flow equalization is estimated to be 10 to 20 percent of the average dry-weather flow.[22] Integration of wet-weather quality control with dry-weather control affords the opportunity for equalization of dry-weather flow since the wet-weather quality, in general, must be accomplished through a combination of storage and treatment. Therefore, if a sewage treatment facility is designed on the basis of peak flow, equalization would result in some excess capacity at this facility. Utilization of this excess capacity can reduce the treatment capacity needed for wet-weather quality control.

Wet-weather quantity control can be accomplished through storage. Utilization of this storage for accomplishing wet-weather quality control can reduce the storage and treatment requirements for wet-weather quality control. A rough estimate of the potential savings by integrating these three purposes can be made as follows.

Let D denote actual sewage flow, mgd, and E´ equal excess capacity through equalization, mgd. Then, using cost data presented by Hasan,[20]

Z_1' = cost of dry-weather control at a secondary plant, dollars per year

= amortized capital costs and annual O & M costs

$$= 118{,}000(D + E')^{0.77} + 55{,}000\ D^{0.83}. \qquad \text{(VI-45)}$$

Assuming D = 10 mgd, E´ = 10 mgd and a per capita sewage flow of 100 gallons per day, computing Z_1' and dividing by area $A = D(\text{mgd})/10^{-4}PD_d$ gives

$$Z_1 = 15.6\ PD_d \qquad \text{(VI-46)}$$

where Z_1 = annual cost of dry-weather quality control, dollars per acre, and

PD_d = developed population density, persons per acre.

Also,

Z_2 = annual cost of wet-weather quality control, dollars per acre

$$= c_S S^* + c_T[T_1 + (T_2 - T_1)e^{-KS^*}], \qquad \text{(VI-47)}$$

where all terms are as defined earlier,

and

Z_3 = annual cost of wet-weather quantity control, dollars per acre,

$$= c_S V, \qquad \text{(VI-48)}$$

where V = storage volume required for wet-weather quantity control, inches,

= $CR'(i)$, with

CR' = runoff coefficient in developed state minus runoff coefficient in undeveloped state, and

i = 24-hour rainfall for design frequency, inches.

If dry-weather quality control and wet-weather quality control are integrated, then

Z_{12} = joint annual cost of two purposes, dollars per acre,

$$= 15.6\ PD_d + c_E E + c_S S^* + c_T[\ T_1 - E\ + (T_2 - T_1)e^{-KS^*}] \qquad \text{(VI-49)}$$

where E = excess capacity per total area, inches per hour = $1.535 \times 10^{-4} PD_d$ assuming $E' = 10$ mgd generated using 100 gal/capita-day and converting from mgd to ac-in./hr; and

c_E = annual cost of treating E at dry-weather plant,

= \$1,960 per acre-inch/hour (assumed using \$3,000 per mgd from analysis of treatment costs).

If wet-weather quality control is integrated with wet-weather quantity control, then

Z_{23} = joint annual cost of two purposes, dollars per acre,

$$= c_S S^*_2 + c_T[T_1 + (T_2 - T_1)e^{-KS^*_2}] \qquad \text{(VI-50)}$$

where $$S^*_2 = \max\left(V, \frac{1}{K} \ln \left[\frac{c_T}{c_S} K(T_2 - T_1)\right], 0\right). \qquad \text{(VI-51)}$$

It is assumed that dry-weather control cannot be integrated with wet-weather quantity control. Therefore,

Z_{13} = joint annual cost of two purposes, dollars per acre,

$$= Z_1 + Z_3 \tag{VI-52}$$

$$= 15.6 \ PD_d + c_S V. \tag{VI-53}$$

If all three purposes are integrated, then

$$Z_{123} = 15.6 \ PD_d + c_E E + c_S S_2^* + c_T[\,T_1 - E + (T_2 - T_1)e^{-KS_2^*}]. \tag{VI-54}$$

To determine the potential savings in wet-weather quality control due to integrating this purpose with the other two purposes, it is first necessary to apportion the total cost among the three purposes. For cost allocation, the use of facility method, most commonly applied in the wastewater field, cannot be applied in this case because there is no single facility utilization parameter that is common to all three purposes. Hasan has demonstrated that the alternative cost method is appropriate for cost allocation.[20] Briefly, the alternative cost method assigns each purpose its separable cost plus a portion of the joint or non-separable cost on the basis of alternative cost. These costs are defined as follows:

SC_i = separable cost to purpose i

= cost of the total project minus cost of the project with purpose i excluded, and

NSC = non-separable cost

= total project cost minus sum of the separable costs to all purposes.

Then,

$$\phi_i = SC_i + \gamma_i(NSC) \tag{VI-55}$$

where ϕ_i = cost allocation to purpose i, and

γ_i = fraction of the non-separable cost assigned to i.

In light of the above discussion, the cost assigned to stormwater quality control, ϕ_2, (purpose 2) is as follows:

$$\phi_2 = SC_2 + \gamma_2(NSC) \tag{VI-56}$$

where $$SC_2 = Z_{123} - Z_{13} \qquad \text{(VI-57)}$$

$$NSC = Z_{123} - \sum_{i=1}^{3} SC_i \qquad \text{(VI-58)}$$

$$= Z_{12} + Z_{13} + Z_{23} - 2Z_{123}, \text{ and}$$

$$\gamma_2 = \frac{Z_2 - SC_2}{(Z_1 + Z_2 + Z_3) - \sum_{i=1}^{3} SC_i} \qquad \text{(VI-59)}$$

$$= \frac{Z_2 - (Z_{123} - Z_{13})}{(Z_1 + Z_2 + Z_3) - [(Z_{123} - Z_{23}) + (Z_{123} - Z_{13}) + (Z_{123} - Z_{12})]}. \qquad \text{(VI-60)}$$

Then, the potential savings are $Z_2 - \phi_2$.

The above procedure was used to derive Figure VI-15, Cost Allocation Factors for Five Cities, for the two year storm. The sensitivity analysis reflecting the variations in cost allocation relationship for various frequency storms for region III is presented in Figure VI-16, Effect of Design Storm and Number of Purposes on Cost Allocation Factor for Various Levels of Control. Based on the results in Figure VI-15, the following cost allocation proportions can be used for all urbanized areas.

% Pollutant Control	Cost Allocation Factor, ϕ_2/Z_2
25	0.46
50	0.50
75	0.70
85	0.80

Potential Savings Using Best Management Practices

In addition to using storage-treatment devices to control wet-weather pollution, other options, popularly called best management practices (BMP's), are available. In a related study, Heaney and Nix evaluated the savings in control costs if BMP's are used in conjunction with storage-treatment.[24] The procedure was applied to Anytown, U.S.A., a hypothetical city of one million people whose characteristics were determined based on average values

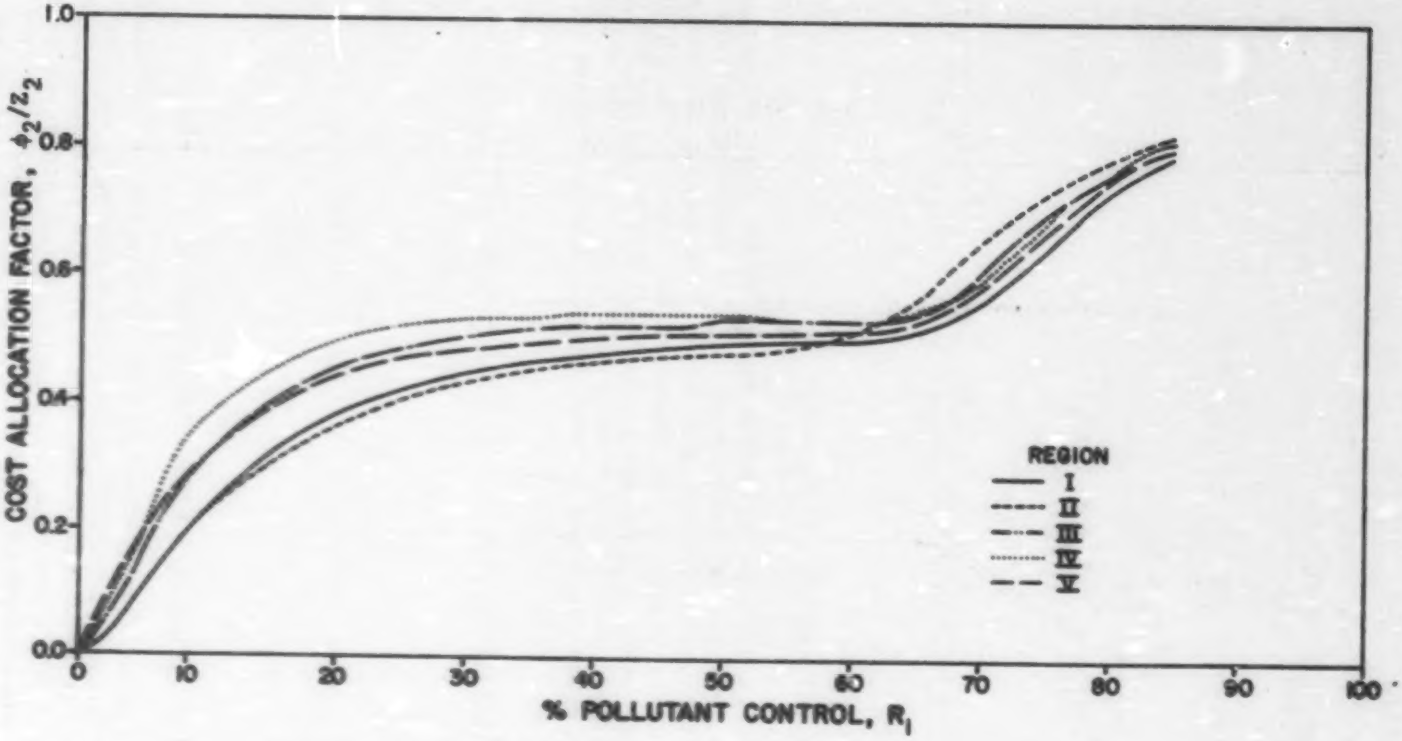


Figure VI-15. Cost Allocation Factors for Five Cities

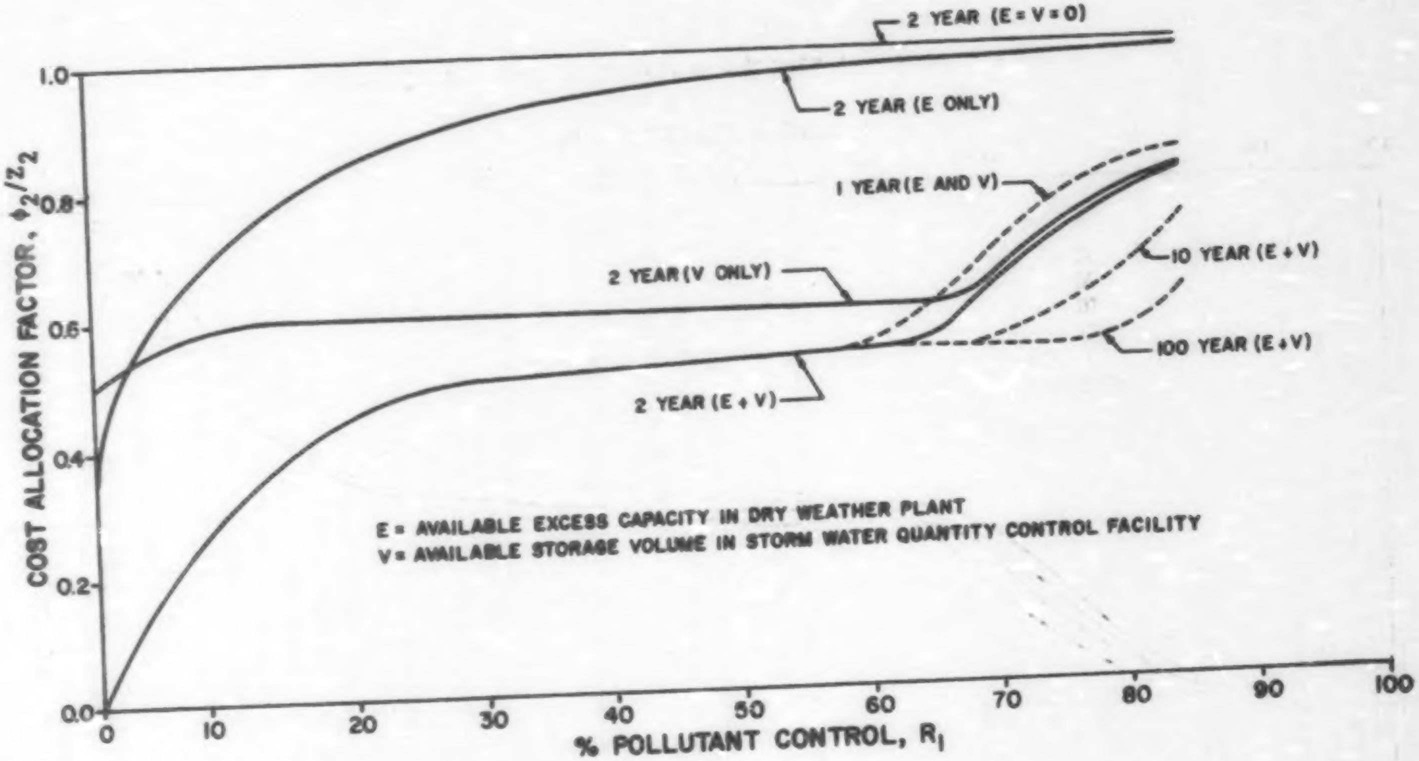


Figure VI-16. Effect of Design Storm and Number of Purposes on Cost Allocation Factor for Various Levels of Control

derived in this study. The results, shown in Table VI-20, Comparison of Annual Cost of Optimal Control Strategy for Anytown, U.S.A. Using Storage-Treatment Alone and in Combination with Best Management Practices, indicate significant savings could be realized by using BMP's in conjunction with storage-treatment devices. These results can be incorporated into the final assessment by multiplying the storage-treatment costs by the % savings shown below.

% Pollutant Control	% Savings Using BMP's
25	54
50	37
75	37
85	39

SUMMARY

The purpose of this assessment is to evaluate the cost of controlling varying levels of wet-weather pollution, emanating from the 149×10^6 people living in urban areas in the United States. Reliable procedures for assessing stormwater pollution are not yet available. Thus, a considerable amount of developmental effort was expended in devising such procedures. Major results are presented, by item, in the next paragraphs.

1. Total Single Purpose Control Costs

Relatively detailed studies in five cities provided the basis for evaluating storage-treatment alternatives for wet-weather control. One year of hourly data was simulated to predict the performance of various storage-treatment configurations. These results were put in analytical form to expedite extrapolation to the other 243 urbanized areas and other urban areas. These results are combined with data on the cost of storage and treatment to derive the optimal mix of storage and treatment to use to obtain a given level of control. The final result is shown in Figure VI-17, Storm Water Pollution Control Costs for the United States. A striking feature of curve A is that it bends upward (convex) indicating increasing incremental costs (particularly at higher levels of control). The primary reason the curve has this shape is due to the disproportionately larger amounts of storage and treatment required to control the larger storms.

Table VI-20. Comparison of Annual Cost of Optimal Control Strategy for Anytown, U.S.A. Using Storage-Treatment Alone and in Combination with Best Management Practices

Type of Sewered Area	% BOD Control	Annual Cost ($ X 10^6/yr)		% Savings Over S-T Only
		Storage-Treatment (S-T) Only	Storage-Treatment and BMP's	
Combined	25	0.94	0.42	55
	50	2.46	1.49	39
	75	7.28	4.03	45
	85	9.22	7.03	24
Storm	25	0.60	0.25	58
	50	1.56	1.00	36
	75	4.64	2.62	44
	85	13.19	5.17	61
Unsewered	25	0.68	0.35	49
	50	1.79	1.17	35
	75	3.50	3.12	11
	85	3.50	3.50	0
Total	25	2.22	1.02	54
	50	5.81	3.66	37
	75	15.42	9.77	37
	85	25.91	15.70	39

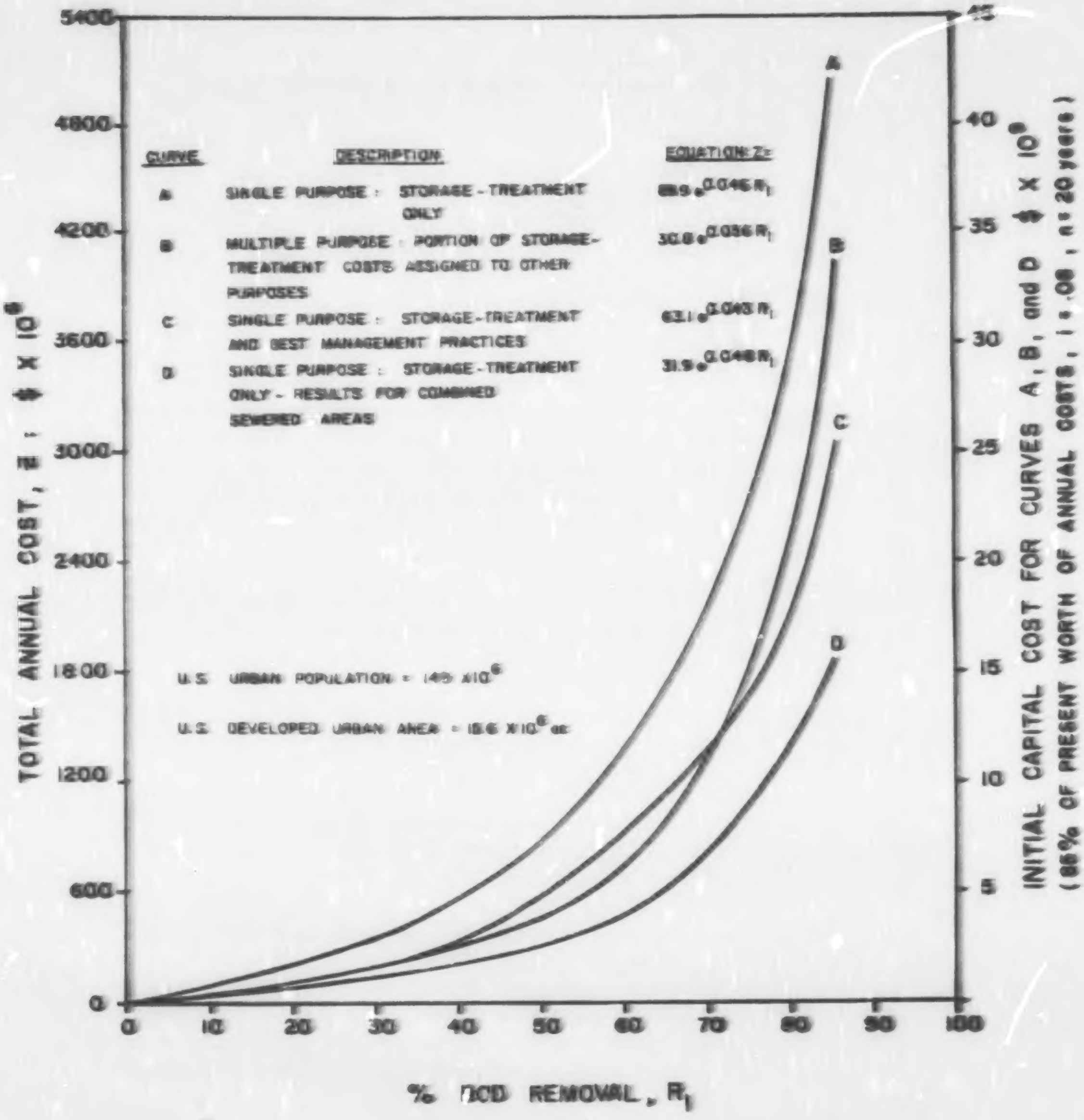


Figure VI-17. Storm Water Pollution Control Costs for the United States

2. Total Multiple Purpose Control Costs

Significant savings can be realized if one integrates dry and wet-weather treatment and storage for quality as well as quantity control. Curve B in Figure VI-17 indicates the cost of stormwater quality control in an integrated system. This result suggests that the potential savings are significant enough to warrant further study in evaluating stormwater systems.

3. Total Costs of Storage-Treatment and Best Management Practices

Potentially significant savings can be achieved by including best management practices (BMP's) in the analysis (curve C). Street sweeping in areas with relatively high pollutant loading rates and sewer flushing where heavy deposition occurs in combined sewers appear to be especially promising as options to storage-treatment. Furthermore, a significant portion of the costs of BMP's could be allocated to other purposes.

4. Tertiary Treatment vs Stormwater Quality Management

A comparison of the marginal costs of tertiary treatment of sewage for further BOD control with initiating control of wet-weather quality indicates that one should initiate some level of wet-weather quality control prior to using tertiary treatment. Of course, a different result would occur if nutrient control is used instead of BOD control. Nevertheless, the relatively low marginal costs of wet-weather control at low levels of control indicate that it should be given serious consideration as an alternative to tertiary treatment.

5. Comparison of Control Costs with Other Studies

Previous studies have indicated that stormwater control is quite expensive. Table VI-21, Control Costs Reported in Other Studies indicates that the 1974 Needs Survey estimated total control costs as $266 billion whereas the more recent National Commission on Water Quality estimate is \$278.6 x 10^9.[25, 26] This assessment indicates initial capital costs ranging from 2.5 billion for 25 percent control to 41.9 billion for 85 percent pollutant control, a small fraction of the above estimates. Two reasons why the estimates vary by such a large amount are discussed below.

Table VI-21. CONTROL COSTS REPORTED IN OTHER STUDIES

Study	Cost Item	Capital Cost: $\$ \times 10^9$
1974 Needs Survey	Combined Sewers[a]	31.1
	Storm[b] Sewers	235.0
	Total	266.1
National Commission on Water Quality[c]	Combined Sewers[d,e]	79.6
	Storm Sewers[d,f]	199.0
	Total	278.6

[a] States developed estimates using various assumptions regarding design storm, unit costs, etc.

[b] Estimate includes collection sewer costs.

[c] Source: Staff Report to the National Commission on Water Quality, Washington, D.C., U.S.G.P.O., 1976.

[d] Used 2 year, 1 hour design storm.

[e] Cost based on disinfection and in-line and off-line storage with primary treatment in effluent limited receiving waters and secondary treatment in water quality limited receiving waters.

[f] Cost based on removal of sediment, bacteria, and associated pollutants. Includes stormwater collection system costs equal to $\$84 \times 10^9$.

A. Collection System Costs -

The NCWQ estimate includes $\$84 \times 10^9$ for constructing storm sewers. This study did not view storm sewers as chargeable to pollution control.

B. Choice of a Design Storm -

The NCWQ studies used control of the two year, one hour storm as the basis for their mean estimate of control costs. The concept of a design storm was not used because it was felt that a continuous characterization in terms of percent of the runoff which could be treated (or events per year) was more appropriate since no accepted design event condition exists which also specifies a design antecedent dry-weather period. Also, sizing storm water quality control units to treat runoff from storm intensities associated with less frequent events, e.g., two year - one hour storm, requires relatively large treatment and storage capacities.

Using 25 years of hourly rainfall data for San Francisco, CA, and Atlanta, GA, the relationship between percent of precipitation "treated" and the design storm was determined. Figure VI-18, Percent of Total Precipitation Volume vs Rainfall Intensity - Atlanta, GA (1948-1972), indicates the percentage of total volume less than or equal to a given value. For example, approximately 65 percent of the total precipitation volume occurs from rainfall rates of 0.30 inch per hour (0.76 cm/hour) or less. Thus, a treatment unit of this capacity could treat the entire precipitation during those hours. It could also treat a portion of the remaining more intense storms. The additional volume treated equals the number of hours during which the precipitation was greater than the indicated treatment rate times the treatment. From Figure VI-19, Percent of Total Precipitation Hours vs Rainfall Intensity - Atlanta, GA (1948-1972), approximately five percent of the rainfall hours exceed 0.30 inch per hour (0.76 cm/hour). The average precipitation in Atlanta is 47.1 inches per year (120 cm/year) occurring during an average

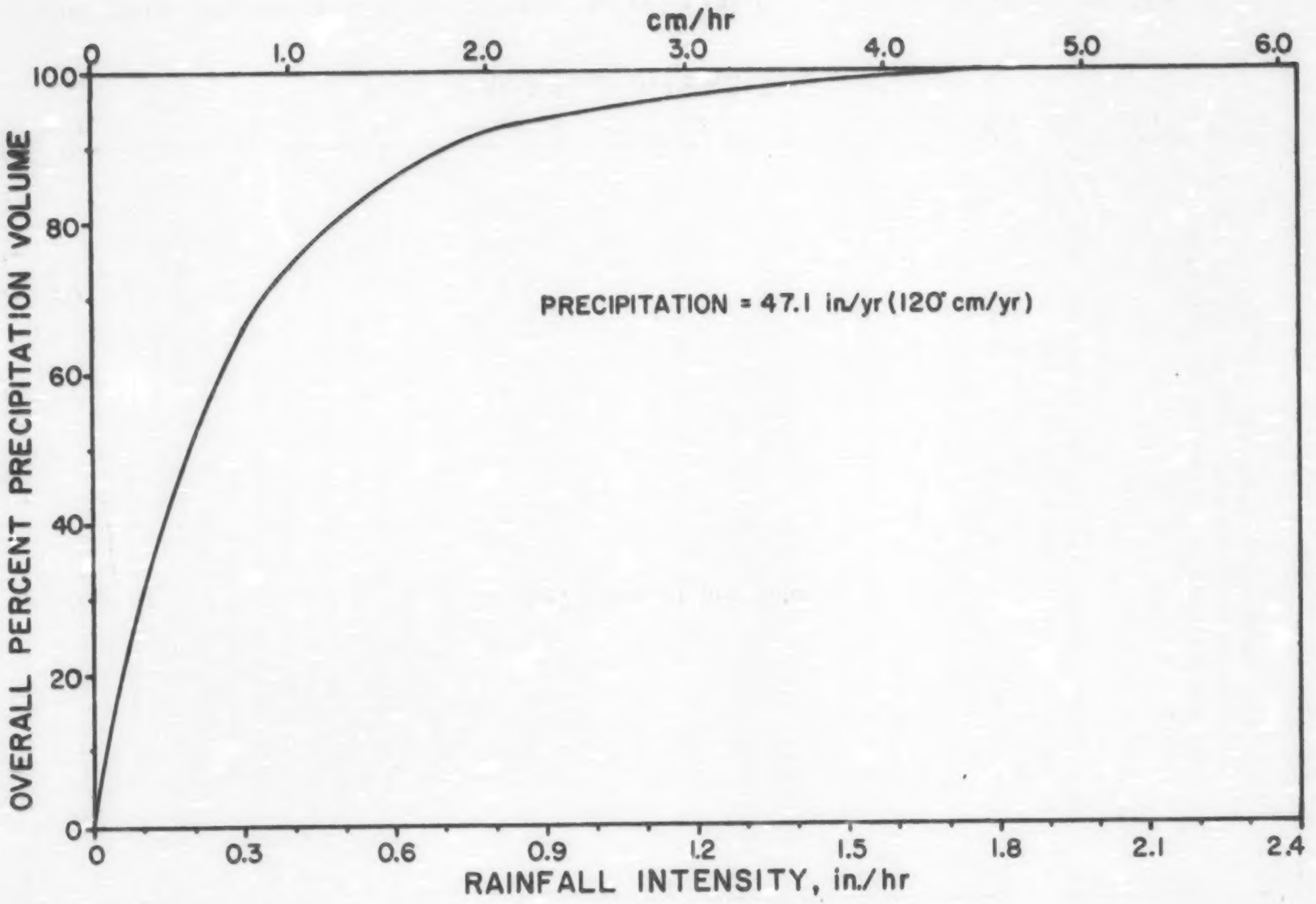


Figure VI-18. Percent of Total Precipitation Volume vs Rainfall Intensity - Atlanta, GA (1948-1972)

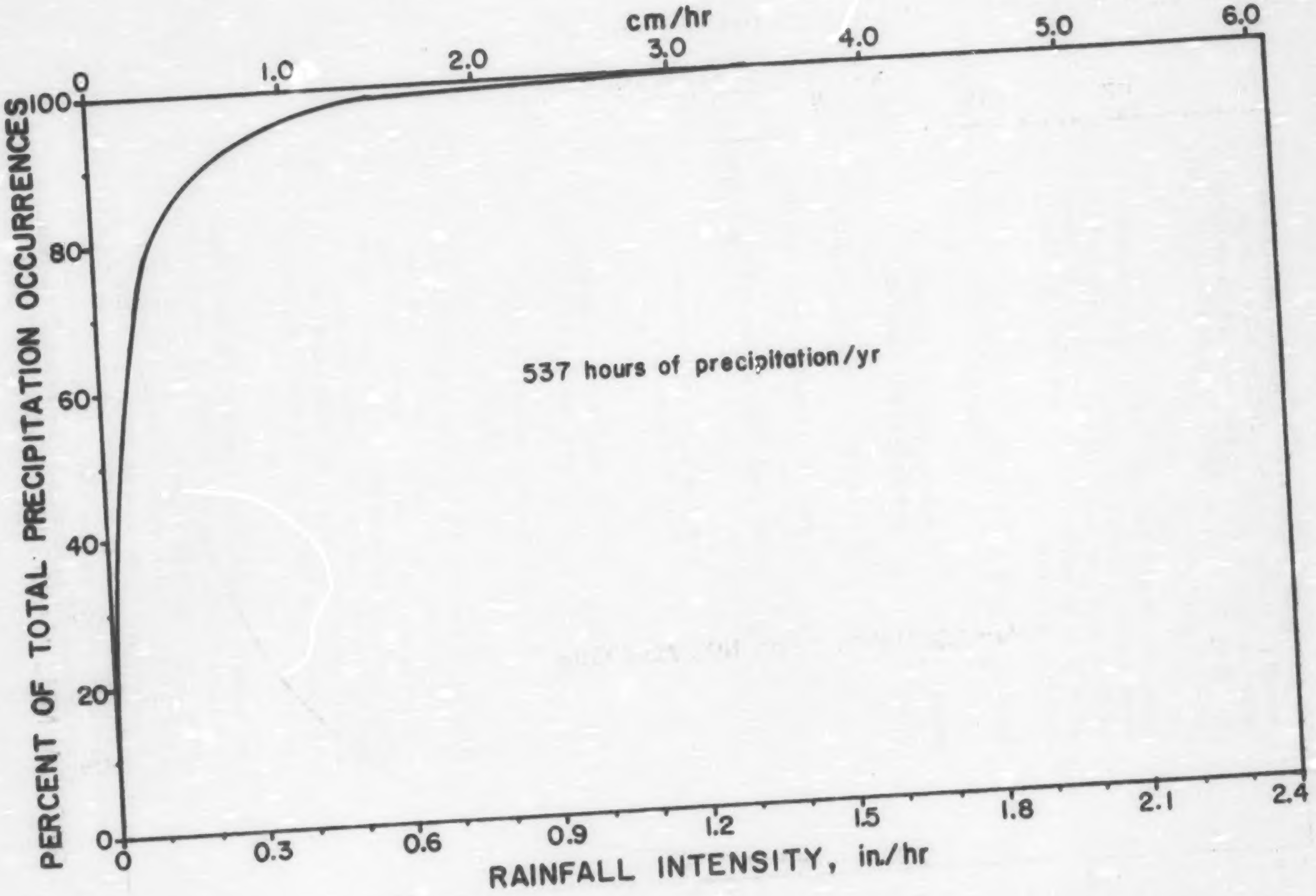


Figure VI-19. Percent of Total Precipitation Hours vs Rainfall Intensity - Atlanta, GA (1948-1972)

of 537 hours per year. Thus, the additional percent volume treated during intensities greater than 0.30 inch per hour (0.76 cm/hour) is 100[0.05(0.30 in./hr)(537 hr/yr)/47.1 in./yr], or 17.1 percent.

Thus, the total percent of volume treated with a unit capable of handling precipitation of 0.30 inch per hour (0.76 cm/hour) is about 65 + 17 = 82 percent. In general, to find percent treated use:

$$PT = F_B + (100 - F_C)(I_T)(N_{TOTAL})/P \qquad \text{(VI-61)}$$

where PT = annual overall percent of precipitation treated,

I_R = rainfall intensity, in./hr,

I_T = design treatment rate, in./hr,

F_B = percent volume for all $I_R \leq I_T$,

F_C = percent of total rainfall hours with $I_R \leq I_T$,

N_{TOTAL} = total number of rainfall hours per year, and

P = average annual precipitation, in./yr.

Note that the result is conservative (the estimate of PT is slightly low) since the frequency analysis has been performed using precipitation volumes and hours rather than runoff volumes and hours. This was done to insure comparison with the NCWQ study in which only precipitation frequencies are reported.

The general results for Atlanta, GA, are shown in Figure VI-20, Overall Percent Precipitation Control vs Rainfall Intensity - Atlanta, GA (1948-1972). Also shown on Figure VI-20 are the intensities for storms ranging in frequency from two weeks to 25 years. Treating at the intensity equal to the two week storm would process over 80 percent of the rainfall volume.

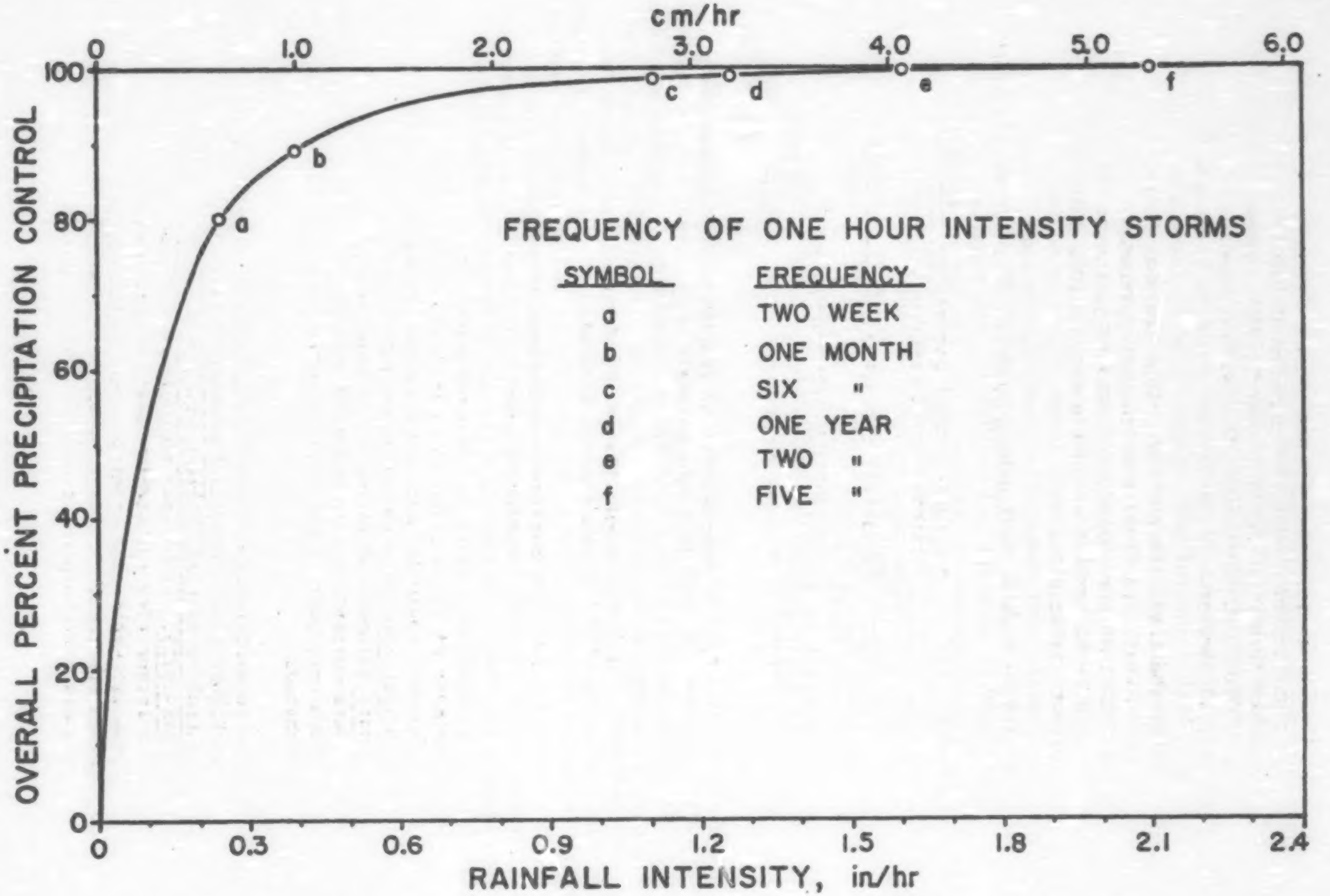


Figure VI-20. Overall Percent Precipitation Control vs Rainfall Intensity - Atlanta, GA (1948-1972)

> Frequencies larger than a month or two approach total capture of the volume. These results indicate that for the NCWQ study, virtually all of the volume would be processed with a control unit operating at an intensity associated with the two year - one hour storm. However, one could control nearly as much precipitation by using a much smaller size control unit. Alternatively, the marginal gain from using these much larger units is quite small. For comparative results, the same three figures were generated using 25 years of hourly data for San Francisco. The results are presented in Figure VI-21, *Percent of Total Precipitation Volume vs Rainfall Intensity - San Francisco, CA (1948-1972)*, Figure VI-22, *Percent of Total Precipitation Hours vs Rainfall Intensity - San Francisco, CA (1948-1972)*, and Figure VI-23, *Overall Percent Precipitation Control vs Rainfall Intensity - San Francisco, CA (1948-1972)*.

Only the future will tell which, if any, of the above cost estimating procedures will provide the most accurate estimate of national control costs. Within the severe data gathering limitations imposed by a national estimate, this study has attempted to make the results as site specific as possible. Improved estimates for a specified city can be obtained using local data. In particular topographic information and knowledge of the number of outfalls permits inclusion of pumping costs and analysis of the optimal combination of control units and interceptor sewers. The interested reader can use a more compact summary of this assessment procedure presented in a report by Heaney, Huber, and Nix to obtain a preliminary estimate for his city or cities.[27]

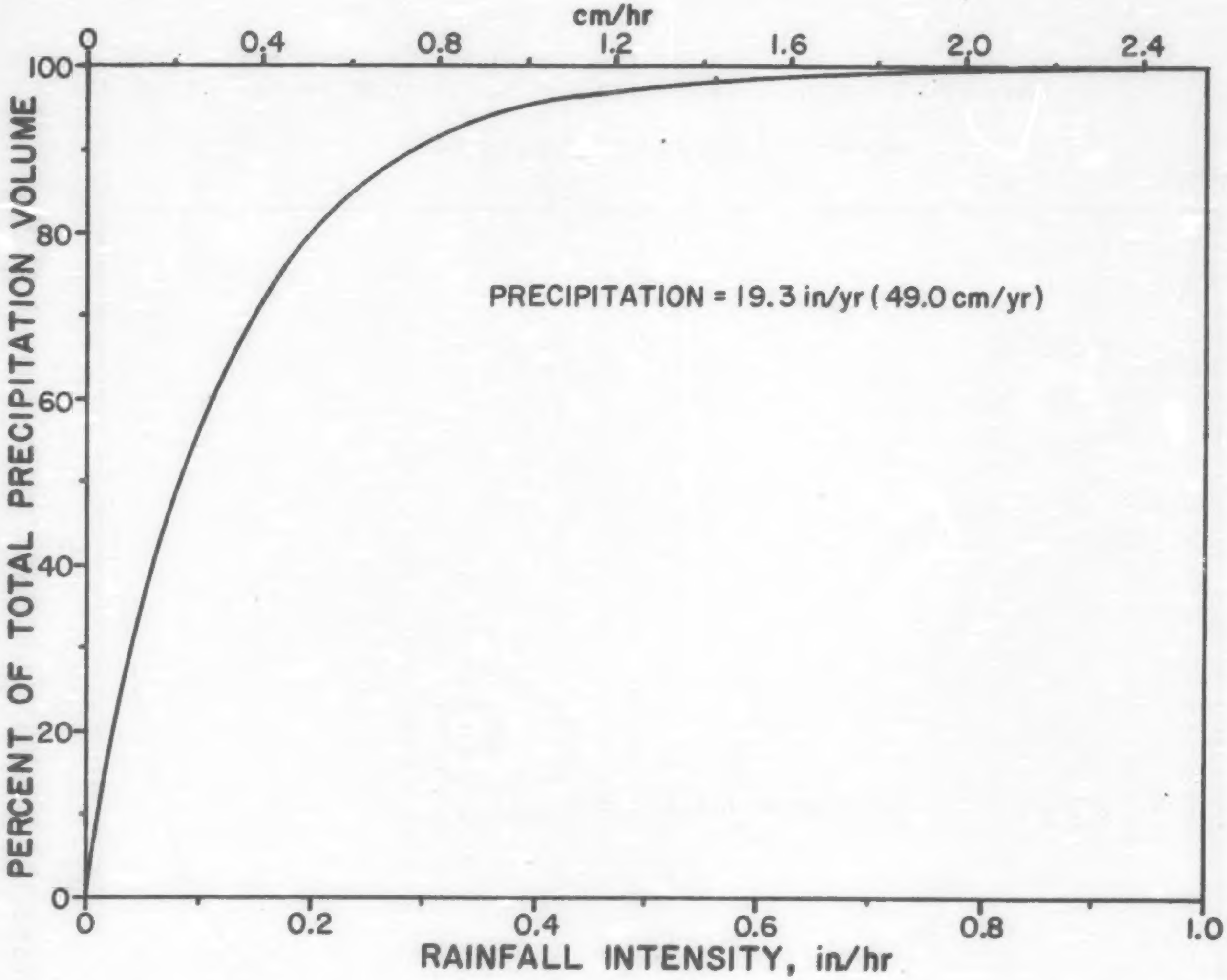


Figure VI-21. Percent of Total Precipitation Volume vs Rainfall Intensity - San Francisco, CA (1948-1972)

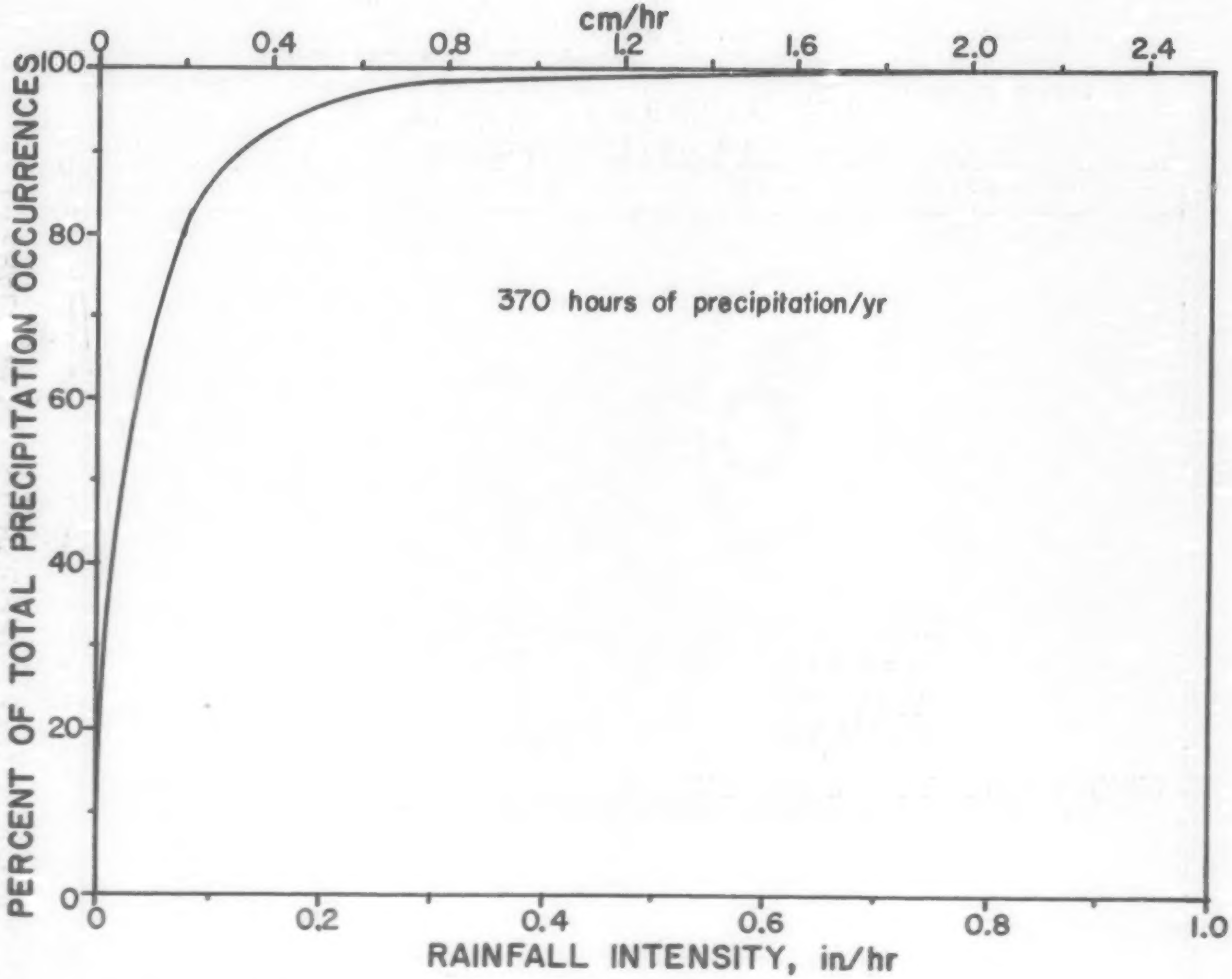


Figure VI-22. Percent of Total Precipitation Hours vs Rainfall Intensity - San Francisco, CA (1948-1972)

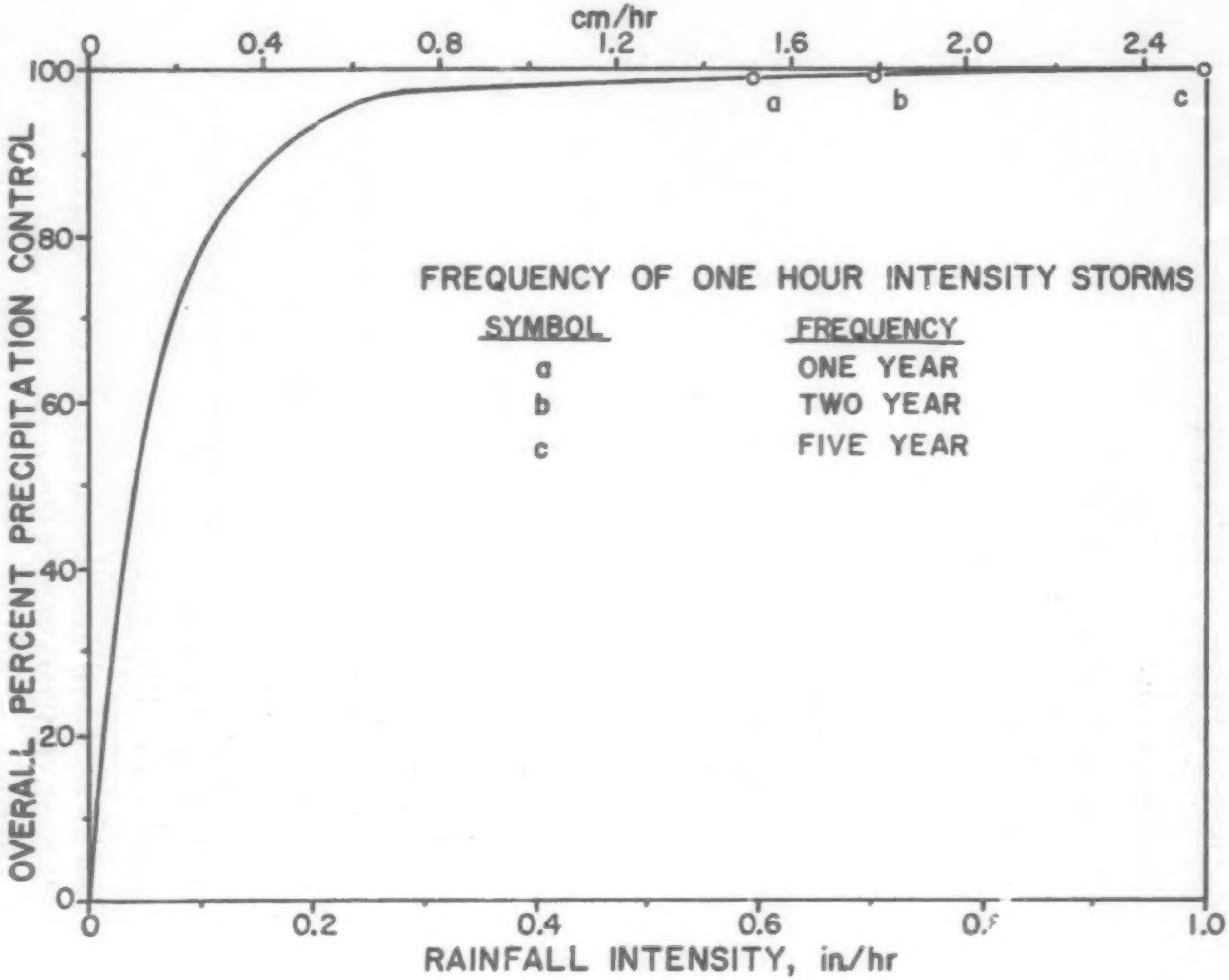


Figure VI-23. Overall Percent Precipitation Control vs Rainfall Intensity - San Francisco, CA (1948-1972)

ABBREVIATIONS AND SYMBOLS

a	Coefficient, inches per hour
A	Catchment or sewerage area, acres
A_1	Combined sewered area, acres
A_2	Storm sewered area, acres
A_3	Unsewered area, acres
A_{tot}	Total developed area, acres
AR	Annual runoff, inches per year
b	Coefficient, inches per hour
BOD	Biochemical oxygen demand
BOD_5	Five-day biochemical oxygen demand
β	Coefficient, percent^{-1}
c	Coefficient, percent R^{-1}
c_E	Unit treatment cost for excess capacity, annual dollars per acre-inch/hour
c_{tert}	Unit incremental cost of tertiary treatment, annual dollars per pound
c_S	Unit cost of storage, annual dollars per acre-inch
c_T	Unit cost of treatment, annual dollars per acre-inch/hour
C	Unamortized capital cost, dollars, also annual unit costs, dollars per acre
C_{tert}	Total annual incremental cost of tertiary treatment plant, dollars
CR	Gross runoff coefficient
CR'	Net runoff coefficient = developed runoff coefficient minus undeveloped runoff coefficient
d	Coefficient, inch^{-1}

D	Actual sewage flow, mgd
E'	Excess capacity at sewage treatment plant, mgd
E	Excess capacity at sewage treatment plant per total area, inches per hour
ENR	Engineering NewsRecord Cost Index
η	Treatment plant efficiency
f	Coefficient, percent R^{-1}
$f(R_1;S,T)$	Production function relating percent pollutant control (R_1) to storage (S) and treatment (T)
F_B	Percent of annual precipitation volume for which $I_R \leq I_T$
F_C	Percent of total annual precipitation hours for which $I_R \leq I_T$
g	Coefficient
γ_i	Fraction of non-separable cost assigned to purpose i
h	Coefficient
i	24-hour rainfall for design frequency, inches
I	Percent imperviousness
I_R	Rainfall intensity, inches per hour
I_T	Design treatment rate, inches per hour
k	Coefficient
K	Coefficient
l	Coefficient
L	Pipe length
m	Urban land use
mg	Million gallons
mgd	Million gallons per day
M	Annual pollutant loading, pounds per acre-year

$\bar{M}$	Average annual pollutant loading, pounds per acre-year
MC	Marginal cost of pollutant removal, annual dollars per pound
MRS_{ST}	Marginal rate of substitution of storage for treatment
NSC	Non-separable cost, annual dollars per acre
N_{TOTAL}	Total number of precipitation hours per year
OE	Number of overflow events per year
p	Coefficient
P	Annual precipitation, inches per year
PD	Gross population density, persons per acre
PD_d	Population density in developed portion of urban area, persons per acre
PT	Annual overall percent of precipitation control (treated)
ϕ_i	Annual cost assigned to purpose i, dollars per year
q	Coefficient
R	Percent runoff control = percent of annual runoff volume passing through treatment unit
R_1	Percent pollutant control (removal)
$\bar{R}_i$	Maximum percent pollutant control (removal)
R_1^*	Optimal percent pollutant control prior to using tertiary treatment
ρ	Fraction of total wet-weather pollution load controlled (removed)
s	Coefficient
S	Storage volume, inches
S*	Optimal storage volume for wet-weather pollution control, inches
S_2^*	Maximum of S* or V, inches
SC_i	Separable cost assigned to purpose i, annual dollars per acre
SS	Suspended solids

T	Treatment rate, inches per hour
T^*	Optimal treatment rate for wet-weather pollution control, inches per hour
T_1	Treatment rate at which isoquant is parallel to the ordinate, inches per hour
T_2	Treatment rate at which isoquant intersects the abscissa, inches per hour
TAC	Total annual costs, dollars per year
v	Coefficient
V	Volume of storage required for wet-weather quantity control, inches
w	Pollutant removal, pounds per acre-year
w_i	Pollutant removal from type of sewered area i, pounds per acre-year
w_i^*	Optimal pollutant removal from type of sewered area i, pounds per acre-year
w^*	Optimal annual pounds per acre of wet-weather pollutants to control (remove) prior to using tertiary treatment, pounds per acre-year
WP	Total annual wet-weather pollution load from developed urbanized area, pounds per year
y	Coefficient
z	Coefficient
Z	Total annual cost, dollars per acre
Z^*	Optimal total annual cost, dollars per acre
Z_p	Annual cost for primary control unit, dollars per acre
Z_s	Annual cost for secondary control unit, dollars per acre
Z_1'	Annual cost of dry-weather quality control, dollars
Z_1	Annual cost of dry-weather quality control, dollars per acre
Z_2	Annual cost of wet-weather quality control, dollars per acre
Z_3	Annual cost of wet-weather quantity control, dollars per acre

Z_{12}	Annual cost of dry-weather quality and wet-weather quality control, dollars per acre
Z_{13}	Annual cost of dry-weather quality control and wet-weather quantity control, dollars per acre
Z_{23}	Annual cost of wet-weather quantity and quality control, dollars per acre
Z_{123}	Annual cost of dry-weather quality, wet-weather quality, and wet-weather quantity control, dollars per acre

REFERENCES

1. American Public Works Association, "Problems of Combined Sewer Facilities and Overflows, 1967," USEPA Report No. 11020---12/67 NTIS-PB 214 469, December 1967.

2. American Public Works Association, "A Study of the Costs Associated with Meeting the Requirements of PL 92-500," Draft Report to National Commission on Water Quality, 1974.

3. James, L. D. and Lee, R. R., Economics of Water Resources Planning, McGraw-Hill, Inc., NY, 1971.

4. Field, R. I. and Struzeski, E. J., Jr., "Management and Control of Combined Sewer Overflows," JWPCF, Vol. 44, No. 7, 1972, pp. 1393-1415.

5. Lager, J. and Smith, W., "Urban Stormwater Management and Technology: An Assessment," USEPA Report EPA-670/2-74-040, NTIS-PB 240 697, December, 1974.

6. Becker, B. C., et al., "Approaches to Stormwater Management," Hittman and Associates, USDI Contract 14-31-001-9025, 1973.

7. Field, R. I., "Treatability Determinations for a Prototype Swirl Combined Sewer Overflow Regulator/Solids-Separator," Proceedings Urban Stormwater Management Seminars, Atlanta, GA, November 4-6, 1975, Denver, CO, December 2-4, 1975, USEPA Report WPD 03-76-04, pp. II-98-II-111, January 1976.

8. Sullivan, R. H., et al., "The Swirl Concentrator as a Grit Separator Device," USEPA Report EPA-670/2-74-026, June 1974.

9. Maher, M. B., "Microstraining and Disinfection of Combined Sewer Overflows - Phase III," USEPA Report EPA-670/2-74-049, NTIS-PB 235 771, August, 1974.

10. Agnew, R. W., et al., "Biological Treatment of Combined Sewer Overflow at Kenosha, Wisconsin," USEPA Report EPA-670/2-75-019, NTIS-PB 242 120, April, 1975.

11. DiToro, D. M., "Statistical Design of Equalization Basins," JEE Div., ASCE, Vol. 10, No. EE6, pp. 917-933, December 1975.

12. Benjes, H., et al., "Estimating Initial Investment Costs and Operation and Maintenance Requirements of Stormwater Treatment Process, USEPA Cont. 68-03-2186 (unpublished), 1975.

13. Wiswall, K. C. and Robbins, J. C., "Implications of On-Site Detention in Urban Watersheds," ASCE Hyd. Div. Conf., Seattle, WA, 1975.

14. Hydrologic Engineering Center, "Urban Stormwater Runoff: STORM," US Army Corps of Engineers, Generalized Computer Program 723-58-L2520, 1975.

15. Stankowski, S. J., "Magnitude and Frequency of Floods in New Jersey with Effects of Urbanization," Special Report 38, USGS, Water Resources Div., Trenton, NJ, 1974.

16. Thornthwaite, C. W. and Mather, J. R., "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance," Drexel Institute of Technology, Publications in Climatology, Vol. 10, No. 3, Centerton, NJ, 1957.

17. Eagleson, P. S., Dynamic Hydrology, McGraw-Hill Book Company, NY, 1970.

18. Grace, R. A. and Eagleson, P. S., "The Synthesis of Short-Time-Increment Rainfall Sequences," MIT Dept. of Civil Eng., Hydrodynamics Lab Report 91, Cambridge, MA, May 1966.

19. Sariahmed, A. and Kisiel, C. C., "Synthesis of Sequences of Summer Thunderstorms Volumes for the Atterbury Watershed in the Tucson Area," Proc. IASH Symp. Use Analog Digital Computers in Hydrol., Vol. 2, pp. 439-447, Tucson, 1968.

20. Hasan, S., Integrated Strategies for Urban Water Quality Management, PhD Dissertation, University of Florida, Gainesville, 1976.

21. Anonymous, "Flow Equalization-Plus for Wastewater Treatment Plants?" Civil Engineering, Vol. 45, No. 9, pp. 66-68, September 1975.

22. Anonymous, "Flow Equalization," USEPA Technology Transfer, 1974.

23. Battelle-Northwest, "Evaluation of Municipal Sewage Treatment Alternatives," Council on Environmental Quality, NTIS-PB 233 489, 1974.

24. Heaney, J. P., and S. J. Nix, "Storm Water Management Model: Level I--Comparative Evaluation of Storage-Treatment and Best Management Practices," USEPA, Cincinnati, OH., 1977 (in press).

25. US Environmental Protection Agency, "Cost Estimates for Construction of Publicly Owned Wastewater Treatment Facilities," 1974 Needs Survey, February 1975.

26. Staff Report to the National Commission on Water Quality, USGPO, 1976.

27. Heaney, J. P., Huber, W. C., and Nix, S. J., "Storm Water Management Model: Level I--Preliminary Screening Procedures," USEPA Report EPA-600/2-76-275, October 1976.

SECTION VII

IMPACT OF URBAN WATER POLLUTION CONTROL ON RECEIVING WATER QUALITY

PROBLEM DEFINITION

Unquestionably, the nationwide commitment toward control of water pollution and the efficient use of available water resources has led to the need for comprehensive and integrated river basin planning. An average annual precipitation of 30 inches (762 mm) constitutes the basic source of water supply for the conterminous US, an area of 3,022,387 square miles (7,827,982 sq kms).[1] This amount corresponds to approximately 4,300 billion gallons per day (16.3×10^9 cu m/day). Surface runoff, interflow and groundwater flow result in an average annual streamflow of about 1,200 billion gallons per day (4.54×10^9 cu m/day).[2] This is a simplified measure of the total available freshwater supply. Estimates of water use in the United States for 1970 indicate that 370 billion gallons per day (1.40×10^9 cu m/day) were withdrawn to satisfy off-channel demand. Of the total withdrawn, 87 billion gallons per day (0.33×10^9 cu m/day) were estimated to be consumed -- that is, water made unavailable for further possible withdrawal by natural evaporation, incorporation into crops and manufactured products, and other causes. For the 5-year period from 1965 to 1970, withdrawals increased by 19 percent and consumptive water use increased 12 percent. It is not difficult to visualize that if withdrawals in 1970 were already 31 percent of the total available supply, and consumption was 7 percent, strict water management practices will be absolutely necessary to cope with an increasing water demand upon a fixed water resource. The quality of a scarce freshwater supply will have an added significance for obvious reasons.

The water quality cycle is a dynamic system existing within each phase of the hydrologic cycle. The amount of pollution entering or leaving a water body is determined by the quantity of flow and concentration of pollutants in each of the hydrologic components of the physical system. The retention of pollutants in the water body is not solely a function of the quantity and quality of hydraulic flows, since it also depends upon the location of the pollutants within the water body. The pollutants exist in the water, bottom sediments, and the aquatic life. When area sources such as bottom sediments are the greatest pollutant contributors, it may be necessary to consider treatment of the water body itself; for example, stream aeration. Thus, one of the initial steps in the planning process is water quality problem identification.

Urban areas represent the centers of most intense human activity. Urban land use is small within a river basin, as evidenced in Table VII-1, Land Use in the United States.[3] Point discharges resulting from commercial, industrial, and residential wastes generally enter the receiving stream within relatively short distances of each other, and in some cases all such wastes are processed by municipal facilities and discharged to the water body at one location. Thus, these continuous waste products are concentrated within a relatively small volume of the receiving water. Intermittent precipitation falling on urban areas becomes contaminated as it enters and passes through or within the manmade environment. The first quality degradation occurs when the rainwater comes into contact with pollutants in the air. Next, the surface runoff passes over ground and building surfaces, carrying suspended sediment from erosion sites and dissolving other impurities. Finally, the stormwater runoff comes into contact with: 1) solid residues deposited from earlier storms throughout the conveyance system and appurtenances; and 2) dry weather flow (DWF) in combined sewer systems. This storm runoff is well mixed with sanitary sewage under conditions of turbulent flow in a combined sewer system, and it eventually discharges to the receiving stream. The degradation undergone by urban stormwater passing through the surface runoff phase of the hydrologic cycle can be several orders of magnitude greater than that experienced by rainwater during the precipitation phase.[4] The pollutants either decompose (nonconservative), accumulate (benthic deposits), or are carried further downstream (conservative, suspended and dissolved matter).

The essence of a rational water quality and quantity management program is the decision making process. The high cost of pollution control facilities, in terms of both energy utilization and financial burden, obligates the planning agency to select the optimal strategy for areawide wastewater management. Such a process must focus on a systematic procedure that identifies and defines: 1) the cause/effect relationships of the physical environment; 2) the economic realities of control alternatives; and 3) the benefits to be derived from implementation of these controls. A preliminary analysis that provides an approximation of system responses to proposed treatment measures should aid the selection of the best strategy for restoration of water bodies to accepted water quality standards. Such an analysis must never be interpreted as other than a guide to be tempered by professional judgment. The mathematical models applied need not incorporate all phenomena but rather should be relevant to the problem under consideration. The problem of specific interest is to assess the separate and combined effects of the major urban sources of water pollution upon the quality of the receiving waters. Oxygen concentration is considered the key to the quality of natural water bodies, although it certainly is not the only water quality indicator.[5] Thus, the relative impact of these wastewater sources is appraised by their effect on the dissolved oxygen concentrations downstream from the urban area.

Table VII-1. LAND USE IN THE UNITED STATES
(US Dept. of Agr. Econ. Rept. 149, 1968)[3]

	Acres	Hectares	Percentage
Privately-owned Land	1,326,642,000	536,892,000	59
Nonfederal Public Land	61,307,000	24,811,000	3
Indian Land	50,400,000	20,397,000	2
Small Water Areas	7,099,000	2,873,000	< 1
Urban and Built-up Areas	60,993,000	24,684,000	3
Federal Land	759,499,000	307,369,000	33
Total Areas, 50 States	2,265,940,000	917,026,000	100

It is of further interest to distinguish clearly between the two types of urban stormwater runoff, separate sewer flow and combined sewer overflow, and their relative pollutional impacts.

In essence, the mathematical model must be responsive to the land use, hydrology, and climatology of the drainage area while performing the following functions:

- generate stormwater runoff pollutant loads and dry-weather sanitary flow pollutant loads;
- simulate the pollutant removal efficiency of various treatment schemes;
- simulate the conveyance system, including mixing in combined sewers of wet-and dry-weather pollutants;
- mix the various pollutant inflow combinations with pollutants already in the receiving water (from upstream sources); and
- predict the oxygen balance of the polluted waters downstream from the waste sources,

subject to the constraints imposed by the quantity and quality of the data base. Each pollution control alternative is weighed on the basis of cost-effectiveness: the annual total cost and the water quality improvement obtained. Within the framework of mathematical modeling is the very important task of verification. An application of the model to Des Moines, Iowa, is presented. Computed values for dissolved oxygen are compared with field measurements.

METHODOLOGY

Characterization of Wastewater Discharges and Polluted Waters

To fully characterize the strength of wastewater discharges and the quality of polluted waters, large and diverse numbers of chemical, physical, biological, and bacteriological methods of analysis have been developed. The most common parameters measured are listed in Table VII-2, Pollution and Contamination Indices. The bacteriological procedures are designed to detect potential health hazards from contamination of the water with human or animal feces. The sampling technique, frequency of sampling, and method of preservation should be tailored to the indicators chosen for measurement. Field observations are extremely valuable for verification of mathematical models. Greater precision may be obtained in the laboratory, but if the sample is unrepresentative, greater accuracy will be achieved by in situ procedures.

Table VII-2. POLLUTION AND CONTAMINATION INDICES

Physical Parameters:

- Temperature
- Turbidity
- Color

Chemical Parameters:

- Oxygen Demand
  - Biochemical Oxygen Demand (BOD)
  - Chemical Oxygen Demand (COD)
  - Total Organic Carbon (TOC)
- Nitrogen Compounds
  - Organic
  - Nitrite
  - Nitrate
- Phosphorus Compounds
  - Ortho Phosphorus
  - Poly Phosphates
- Total Solids
  - Dissolved
  - Suspended
  - Volatile and Fixed
  - Settleable
- Chlorides
- Sulfates
- pH
- Alkalinity
- Hardness
- Heavy Metals
  - Lead
  - Copper
  - Zinc
  - Chromium
  - Mercury

Biological Parameters:

- Plankton
- Periphyton
- Macrophyton
- Macroinvertebrates
- Fish Bioassays

Bacteriological Parameters:

- Total Coliform Count
- Fecal Coliform
- Fecal Streptococci
- Total Plate Count

The wastewater constituents that affect the distribution of dissolved oxygen (DO) in a natural water system are well documented. The oxygen demand of sewage, sewage treatment plant effluent, polluted stormwater runoff or industrial wastes is exerted by three types of materials:[5,6]

1. carbonaceous organic matter oxidized by heterotrophic bacteria for energy and cell synthesis;

2. organic nitrogen compounds hydrolyzed into ammonia-nitrogen (NH_3-N), then oxidized by autotrophic bacteria (Nitrosomonas europaea) to nitrite-nitrogen (NO_2-N), further oxidized by Nitrobacter winogradskyi to nitrate-nitrogen (NO_3-N); and

3. certain chemical reducing compounds (ferrous iron, sulfite, and sulfide) which will react with molecularly dissolved oxygen.

This oxygen demand is the response of aquatic biota to an adequate food supply and is commonly referred to as the biochemical oxygen demand (BOD). The laboratory BOD technique is an empirical bioassay-type procedure: the DO consumed by microbial life in an incubated bottle is measured with respect to time at a specified temperature. The actual environmental conditions of temperature changes, biological population, water movement, sunlight, and zones of aerobic and anaerobic processes cannot be faithfully reproduced in the laboratory. Thus, the "bottled" system, on a kinetic comparison, is completely accurate in representing itself but may be relatively unreliable as a representation of the source from which the sample was taken. The basic assumption that consumption of DO is an absolute and complete parameter of biological decomposition in the BOD bottle constitutes a simplification of complex interactions.

Other laboratory methods have been developed to measure the oxygen demand exerted by organic matter. The chemical oxygen demand (COD) and total organic carbon (TOC) tests are more precise chemical methods, but the analytical results are not accurate if the organic material measured is not equivalent to the organic matter actually being utilized by the microorganisms in the stream. Much can be done to improve the accuracy of the BOD test by using dilution water from the receiving stream, thus introducing a natural "seed" of diverse organisms into the bottle system. With all of its limitations, the BOD procedure is still considered to be the best method for evaluating the effect of waste inputs on the oxygen balance of a stream.[7]

Model Overview

Data for the study area are used to simulate the hypothetical response of the receiving water to the separate and combined effects of BOD waste inputs from: 1) upstream sources, 2) dry-weather urban sources, and 3) wet-weather urban sources. The general concept is illustrated in Figure VII-1, Simplified Configuration of Mixed Waste Inputs to Receiving Water. The urban community served by a separate sewer system will convey stormwater runoff and municipal sewage through conduits which are not connected together. The BOD concentration of the storm sewer runoff is mixed with the dry-weather flow (DWF) and accumulated sewer solids. An interceptor carries the sanitary design flow to the municipal sewage treatment plant. The combined sewer overflow is either given treatment or allowed to discharge directly to the receiving water. Since complete mixing is assumed, the BOD concentrations of the combined sewer overflow (Q_c) and the flow (DWFCMB) intercepted for treatment by the DWF facility are identical. Any degree of treatment desired may be imposed at both the DWF and the WWF treatment plants. The concentration of the combined BOD inputs in the receiving water is given by:

$$BOD_m = \frac{BOD_u Q_u + BOD_d Q_d + BOD_w Q_w}{Q_u + Q_d + Q_w} \qquad \text{(VII-1)}$$

where BOD_m = mixed BOD concentration in receiving water, mg/l,

BOD_u = mixed BOD concentration from sources upstream of urban area, mg/l,

BOD_d = BOD concentration of dry-weather flow treatment plant effluent, mg/l,

BOD_w = BOD concentration of wet-weather flow treatment facility effluent, mg/l,

Q_u = upstream flow, cfs,

Q_d = DWF treated effluent, cfs, and

Q_w = WWF treated effluent, cfs.

The technique for calculation of the quantity and quality of stormwater and combined sewer overflows is discussed in further detail subsequently. The BOD concentrations of the DWF and WWF treated effluents are given by:

$$BOD_d = \frac{[BOD_f \cdot DWFSEP + BOD_c \cdot DWFCMB](1-R_d)}{DWFSEP + DWFCMB} \qquad \text{(VII-2)}$$

$$BOD_w = \frac{[BOD_s \cdot Q_s + BOD_c \cdot Q_c](1-R_w)}{Q_s + Q_c} \qquad \text{(VII-3)}$$

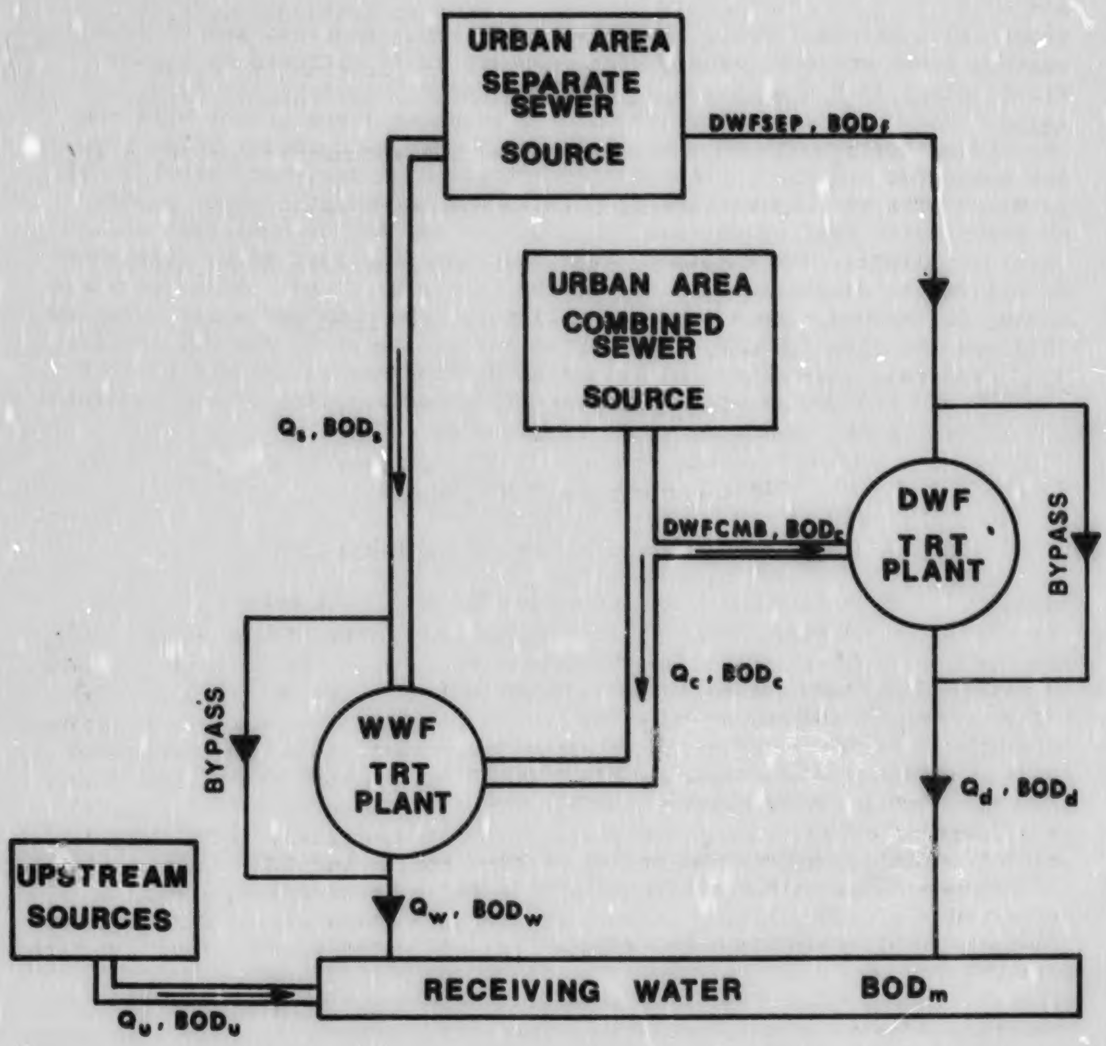

URBAN AREA
SEPARATE SEWER SOURCE
DWFSEP, BOD$_f$
URBAN AREA
COMBINED SEWER SOURCE
Q$_s$, BOD$_s$
DWFCMB, BOD$_c$
DWF TRT PLANT
BYPASS
Q$_c$, BOD$_c$
BYPASS
WWF TRT PLANT
Q$_d$, BOD$_d$
UPSTREAM SOURCES
Q$_w$, BOD$_w$
RECEIVING WATER
BOD$_m$
Q$_u$, BOD$_u$

Figure VII-1. Simplified Configuration of Mixed Waste Inputs to Receiving Water

where BOD_f = BOD concentration of municipal sewage, mg/l,

BOD_c = mixed BOD concentration in the combined sewer, mg/l,

BOD_s = BOD concentration of urban stormwater runoff, mg/l,

DWFSEP = DWF contribution from separate sewer area, cfs,

DWFCMB = DWF contribution from combined sewer area, cfs,

Q_s = urban runoff carried by the separate storm sewer, cfs,

Q_c = combined sewer flow , cfs,

R_d = fraction removal of BOD achieved by the DWF treatment facility, and

R_w = fraction removal of BOD achieved by the WWF treatment facility.

The initial conditions of BOD in the river are defined by equation VII-1, and the hypothetical impact on the oxygen balance of the receiving stream is estimated by using simplified mathematical modeling approaches. The total hours of runoff-producing rainfall throughout the year are separated into storm events by defining a minimum interevent time. The procedure is discussed in detail subsequently. For a given storm event, the runoff and pollutant loads are summed and the critical DO deficit is estimated as a function of several stream parameters: temperature, flow, oxygen concentration, deoxygenation and reaeration rates, and BOD concentrations. The minimum DO is calculated subsequently and a frequency analysis is performed. Stream velocity is computed as a function of the discharge and the time and distance to each critical deficit point are obtained for each event.

The options used for the simulations include:

1. five inflow combinations:
   - a. river flow + DWF
   - b. river flow + DWF + separate flow
   - c. river flow + DWF + combined flow
   - d. river flow + separate flow + combined flow
   - e. river flow + separate flow + combined flow + DWF,
2. four DWF treatment rates (variable),
3. three WWF treatment rates (variable), and

4. three fractions of measured upstream flow

may be investigated.

Item 4 is included as a model option to investigate whether the relative impact of urban stormwater runoff is most significant in the upstream portions of river basins. This effect may be simulated by simply reducing the upstream flow to any desired fraction of its actual measured value. Thus, discharge into a dry river bed may be studied.

Technique for Calculation of Urban Runoff Quantity and Quality

This section briefly describes the methods used to generate storm runoff and pollutant concentrations. The Hydrologic Engineering Center model, STORM[8], is utilized to obtain hydrographs and pollutographs for Des Moines for the year 1968 on an hourly time step.

Urban Runoff Quantity --

As described in Section VI, STORM computes urban runoff as a function of land use and rainfall/snowmelt losses:

$$AR_u = CR_u(P_u - f_u) \tag{VII-4}$$

where AR_u = urban area runoff, in./hr,

CR_u = composite runoff coefficient dependent on urban land use,

P_u = hourly rainfall/snowmelt in inches over the urban area, and

f_u = available urban depression storage, in.

A maximum depression storage of a hundredth of an inch (0.25 mm) is assumed for Des Moines, Iowa. The hourly urban runoff values, expressed in cfs, are saved in a file for later recall by the simplified mathematical model.

Urban Runoff Quality --

The basic water quality parameters modeled by STORM are suspended and settleable solids, BOD, total nitrogen (N), and total phosphate (PO_4). It is important to emphasize that the BOD values are expressed in terms of the standard BOD_5 test: incubation at a temperature of 20°C for 5 days. These values represent most of the carbonaceous oxygen demand exerted by organic matter present in the urban runoff, and include the BOD contribution from suspended and settleable solids. The BOD loading rates generated by STORM are based on land use and other factors such as number of dry days without runoff since the last storm and the street sweeping intervals.

However, these loading rates were calibrated against yearly averages and single storm values obtained from a detailed study of Des Moines by Davis and Borchardt.[9] The hourly BOD_5 pollutographs, in pounds per hour and mg/l, are also saved in a digital computer file for later recall by the receiving water simulation.

Definition of an Event

As stated previously, rainfall input to STORM is prepared as a sequence of consecutive hourly values (including zeros for no measurable precipitation). These inputs are used by STORM to generate the corresponding series of hourly urban runoff. The basic approach to define a wet-weather event is to analyze the hydrologic time series and establish the minimum number of consecutive dry-weather hours (DWH) that separates independent storm events. The independence of these storm events is not strictly climatological and is discussed later. The dry-weather hours refer to periods during which no runoff was produced. Thus, depression storage and evaporation rates must be satisfied before any runoff is generated by STORM.

Two techniques are used to analyze the hydrologic time series: 1) an analytic approach, autocorrelation, and 2) a graphic procedure. The precipitation time series is presented in Figure VII-2, Point Rainfall for Des Moines, Iowa. The abscissa represents the 10-month period, in hours, from March 1 to December 30, 1968. An examination of the rainfall record provides considerable insight as to the storm groupings, their intensity and duration, and frequency of occurrence. The broken line on the abscissa indicates dry-weather periods at least 9 hours in length. Figure VII-2 provides necessary information to apply both techniques and define a minimum interevent time.

For hydrologic processes, it is practical to estimate the autocorrelation coefficients by an open-series approach:[10,11]

$$r_I(k) = \frac{\sum_{i=1}^{n-k} x_i x_{i+k} - \frac{1}{n-k}\left[\sum_{i=1}^{n-k} x_i\right]\left[\sum_{i=k+1}^{n} x_i\right]}{\left[\sum_{i=1}^{n-k} x_i^2 - \frac{1}{n-k}\left(\sum_{i=1}^{n-k} x_i\right)^2\right]^{0.5}\left[\sum_{i=k+1}^{n} x_i^2 - \frac{1}{n-k}\left(\sum_{i=k+1}^{n} x_i\right)^2\right]^{0.5}} \quad \text{(VII-5)}$$

where $r_I(k)$ = sample estimate of lag-k autocorrelation coefficient for hydrologic process I,

x_i = discrete data series (observations) of hydrologic process I, for $i = 1,2,\ldots,n$,

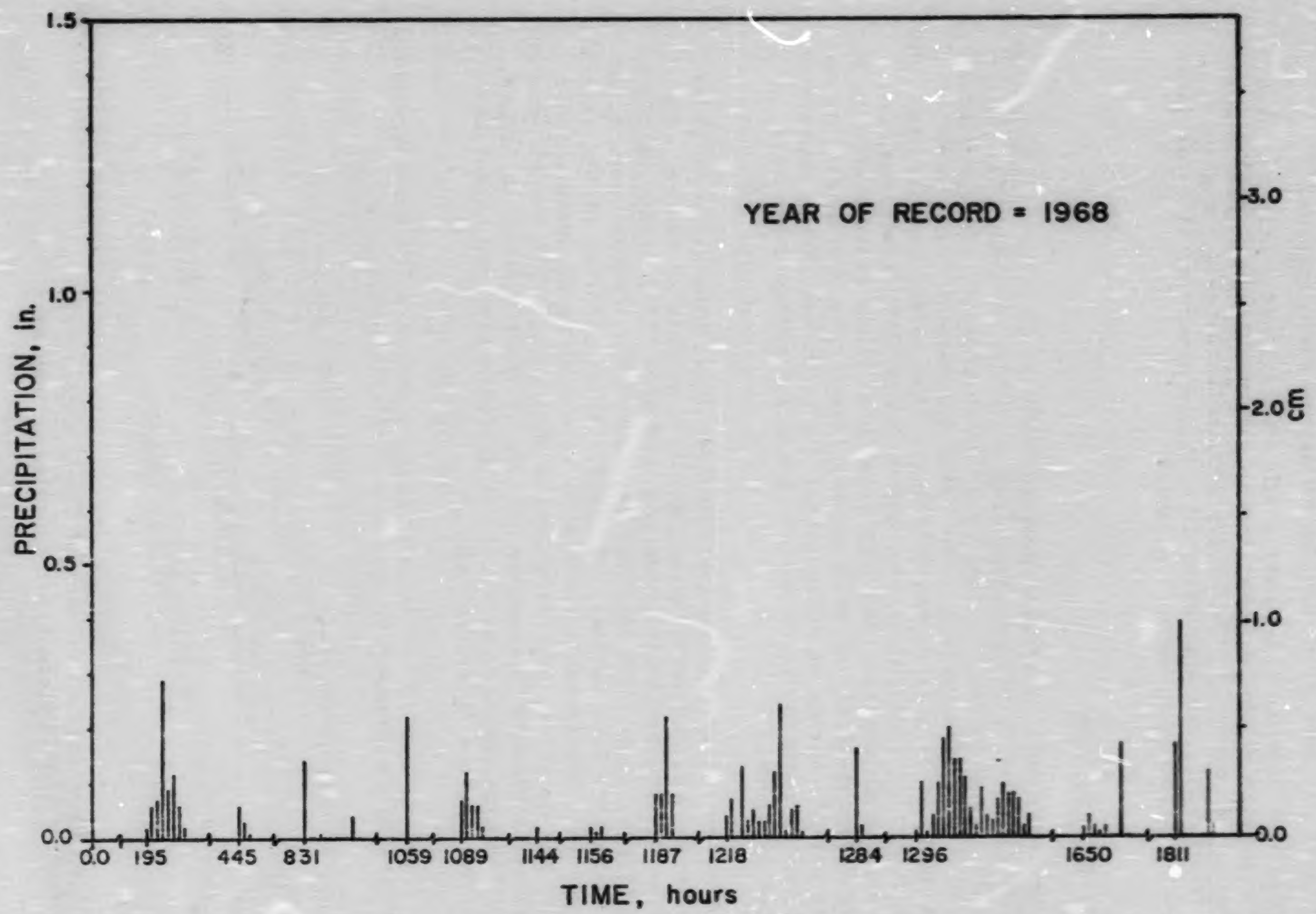


Figure VII-2. Point Rainfall for Des Moines, Iowa

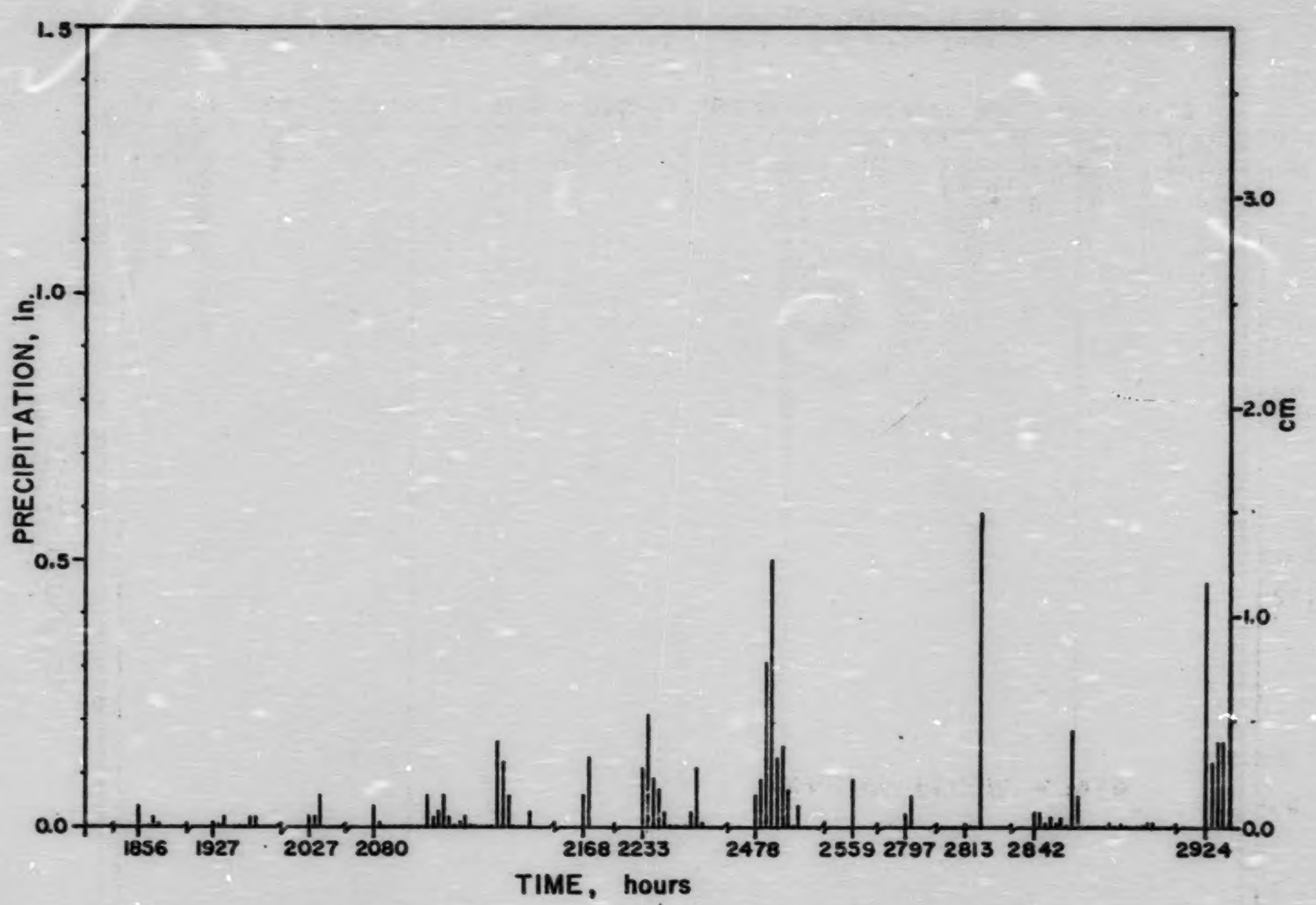


Figure VII-2 (continued). Point Rainfall for Des Moines, Iowa.

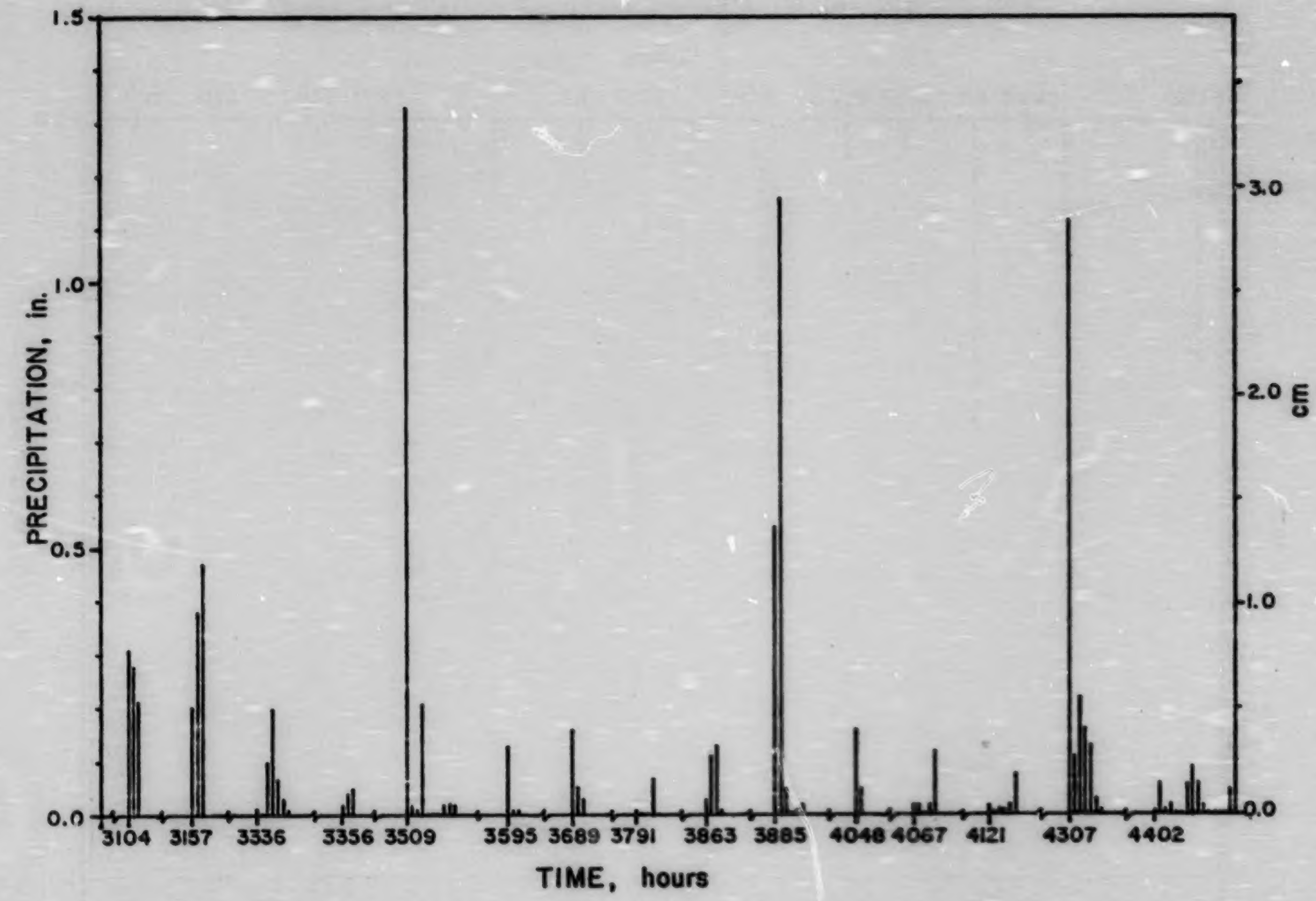


Figure VII-2 (continued). Point Rainfall for Des Moines, Iowa.

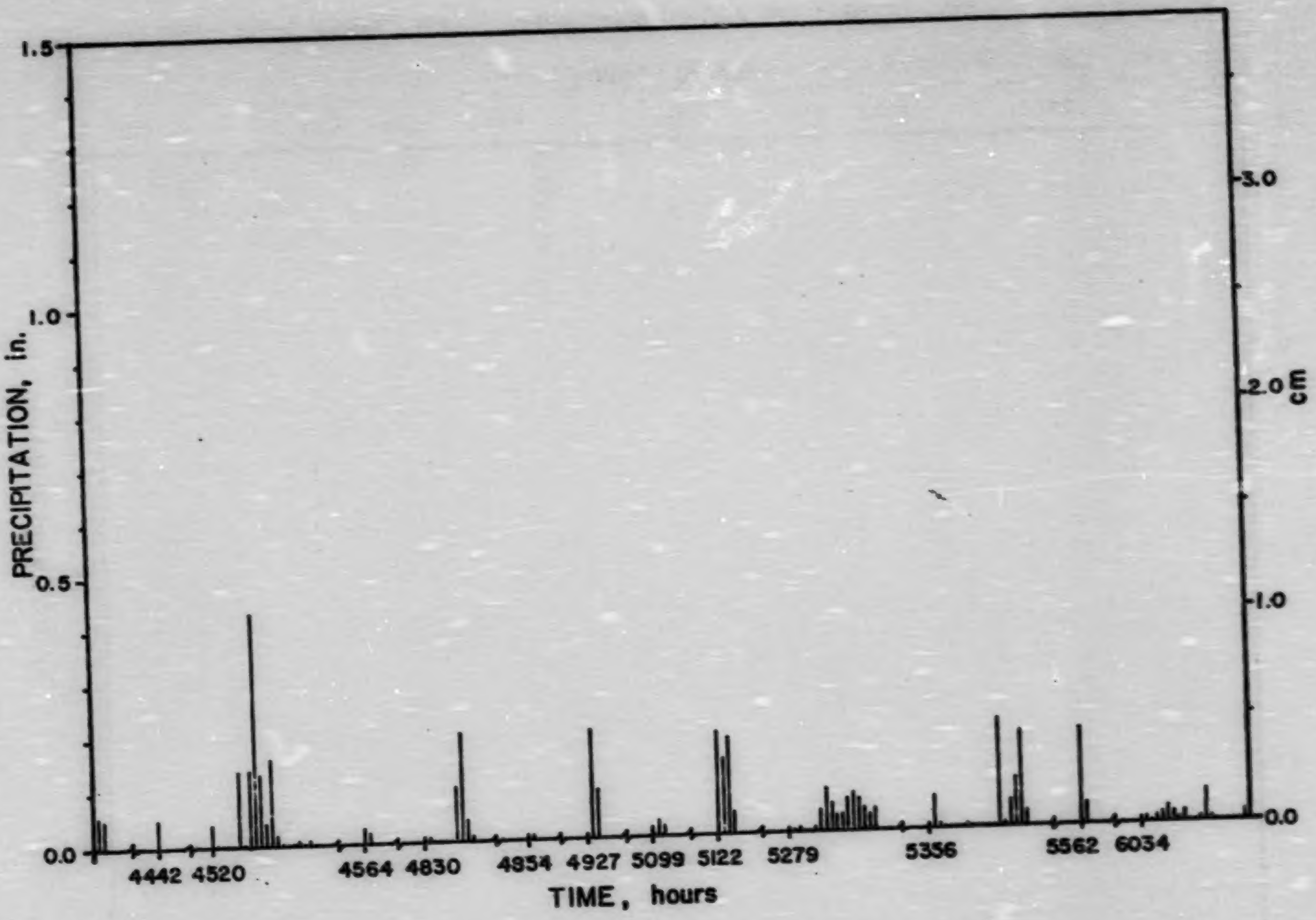


Figure VII-2 (continued). Point Rainfall for Des Moines, Iowa.

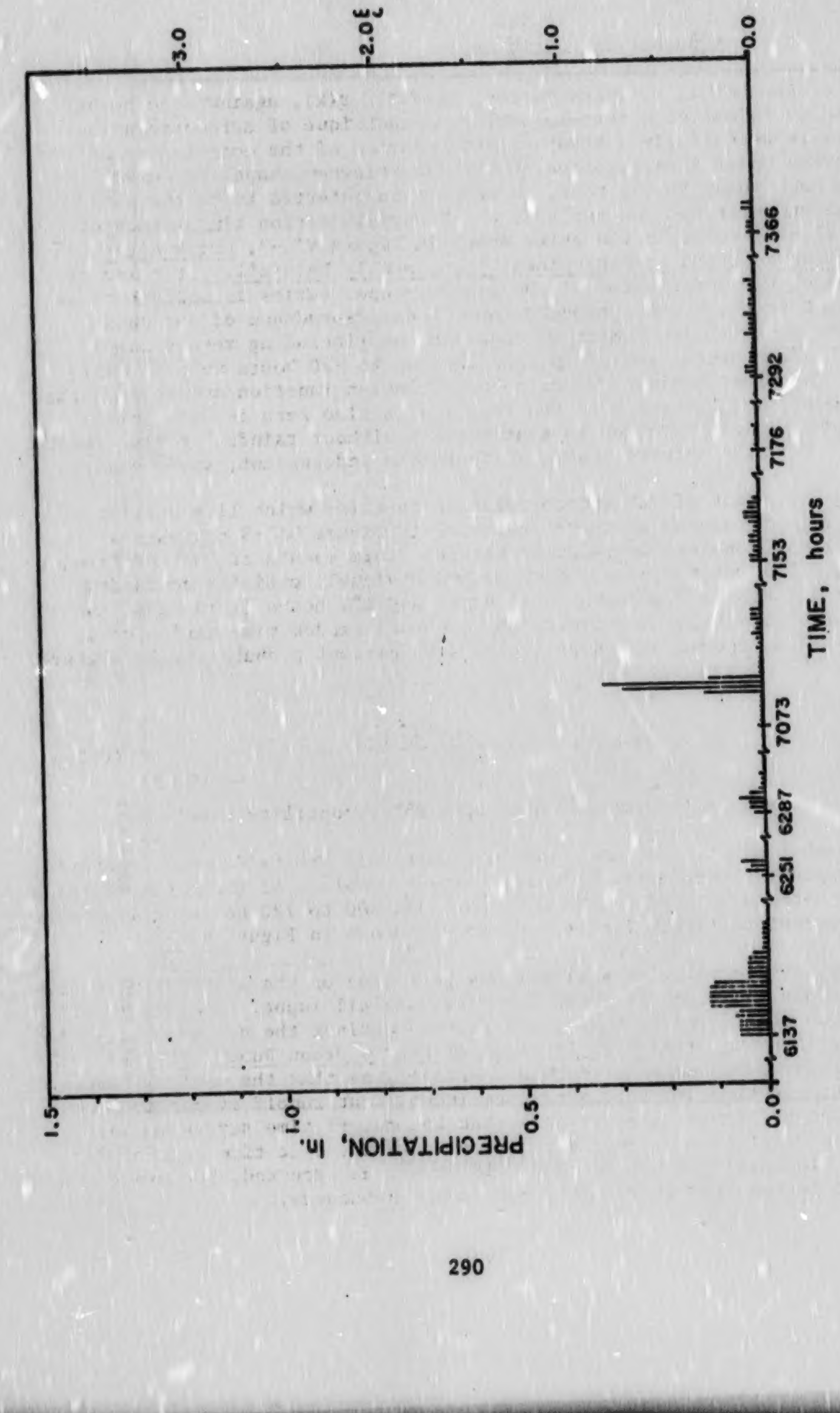


Figure VII-2 (continued). Point Rainfall for Des Moines, Iowa.

n = total number of data points or observations, and

k = number of hourly lags.

A plot of the serial correlation coefficients, $r(k)$, against the number of lags, k, is called a correlogram. The technique of autocorrelation analysis is essentially a study of the behavior of the correlogram of the process under investigation.[12] The correlogram shape, or curve joining each point to the next, is henceforth referred to as the autocorrelation function. An analysis of the precipitation time series of Figure VII-2 results in the curve shown in Figure VII-3, Lag-k Autocorrelation Function of Des Moines, Iowa, Hourly Rainfall. At a lag of zero hours, the correlation of the discrete open series is unity because this point on the curve represents the linear dependence of the data series on itself. The number of observations (including zero values) totals 7,372 consecutive values, and lags up to 720 hours were investigated. The first minimum of the autocorrelation function occurs at a lag of 10 hours, and the value of the function is also zero at this point. The physical interpretation is that periods without rainfall for at least 10 hours separate uncorrelated, and therefore independent, storm events.

Actually any point of the autocorrelation function which lies outside of the 95 percent tolerance limits indicated in Figure VII-3 suggests a significantly non-zero correlation between storm events at that particular time lag. The Des Moines rainfall record obviously exhibits nonrandom behavior at lags of 377 hours (∿ 16 days) and 421 hours (∿ 18 days) in particular. The tolerance limits for a normal random time series of n values, and an open-series approach at a 95 percent probability level, are given by:[10]

$$TL\ (95\%) = \frac{-1 \pm 1.645\sqrt{n-k-1}}{n-k} \qquad \text{(VII-6)}$$

where TL(95%) = tolerance limits at a 95% probability level.

As the number of lags, k, increases the tolerance limits diverge. However, the divergance is not noticeable for large n. Values of the autocorrelation function between lags of 100 to 300 hours and 500 to 720 hours fell between the 95 percent tolerance limits and are not shown in Figure VII-3.

Similarly, autocorrelation analysis was performed on the sequence of hourly runoff values generated by STORM from the rainfall input. The lag-k serial correlation coefficients, $r_Q(k)$, are plotted against the number of lags in Figure VII-4, Autocorrelation Function of Hourly Urban Runoff for Des Moines, Iowa. The analytic technique establishes that the minimum interevent time of consecutive DWH that separates independent runoff events is 9 hours. Examination of Figure VII-4 reveals that the runoff time series is not purely random either. Linear dependence is observed at time lags of 377 hours (∿ 16 days) and 436 hours (∿ 18 days), as expected, because of the high correlation between rainfall and runoff processes.

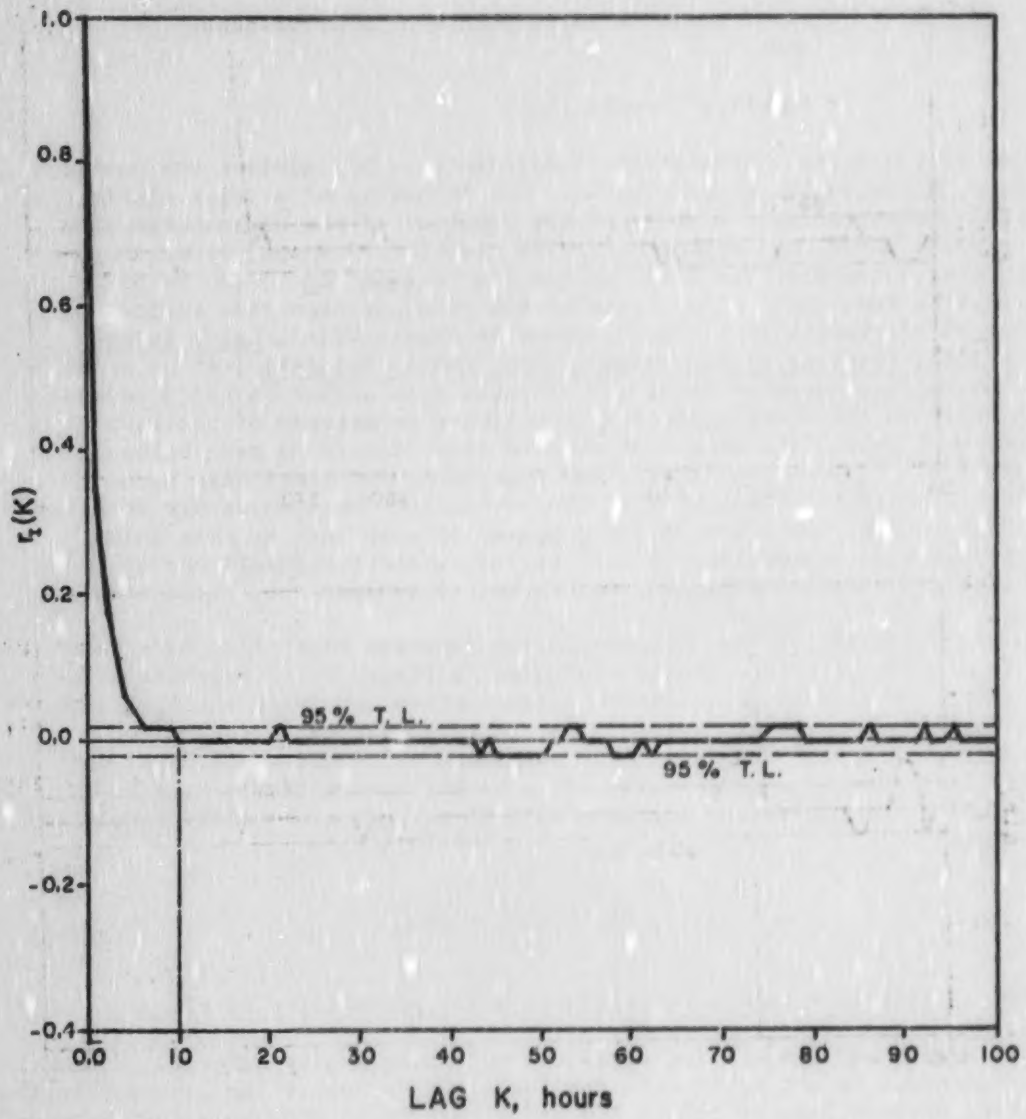


Figure VII-3. Lag-k Autocorrelation Function of Des Moines, Iowa, Hourly Rainfall, 1968.

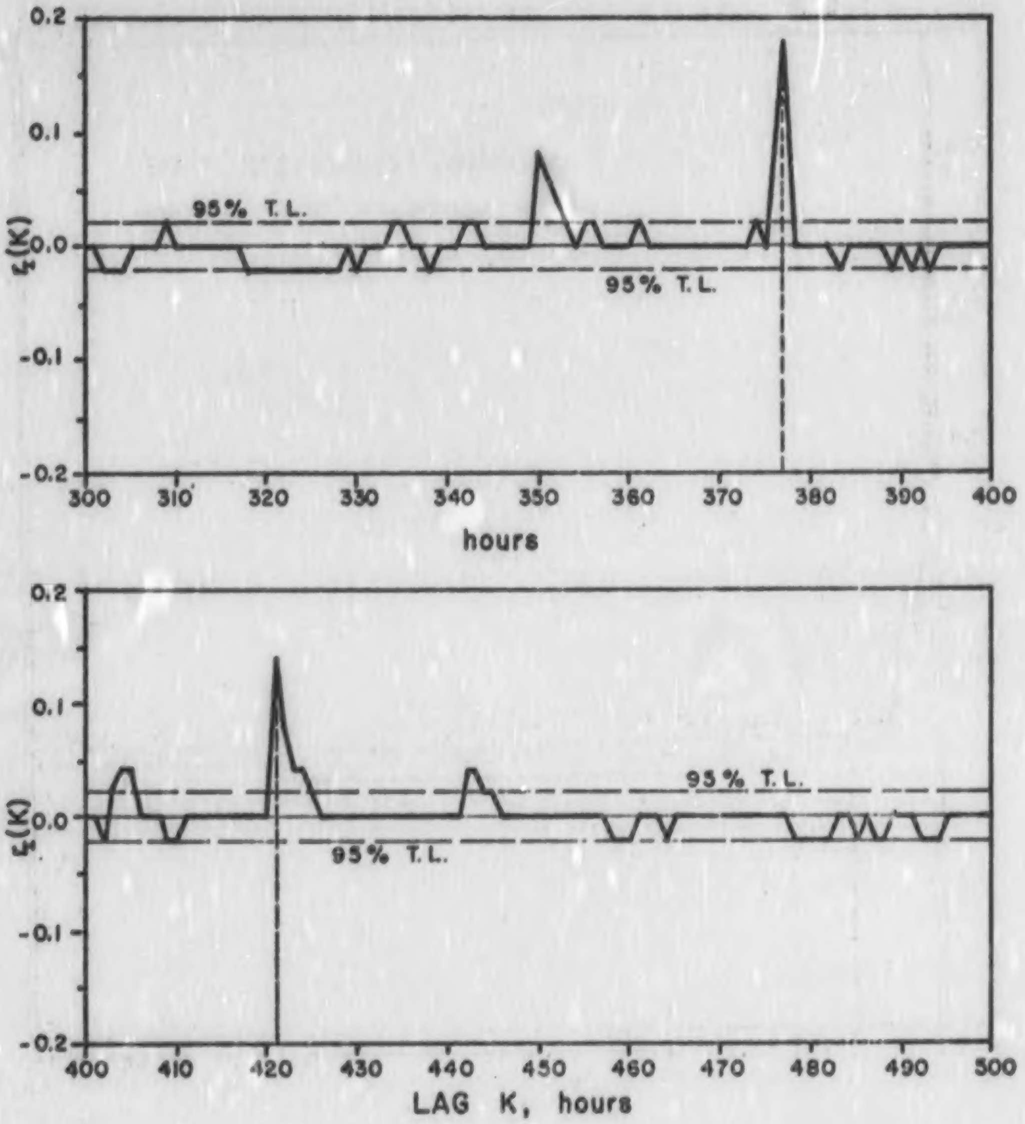


Figure VII-3 (continued). Lag-k Autocorrelation Function of Des Moines, Iowa, Hourly Rainfall, 1968.

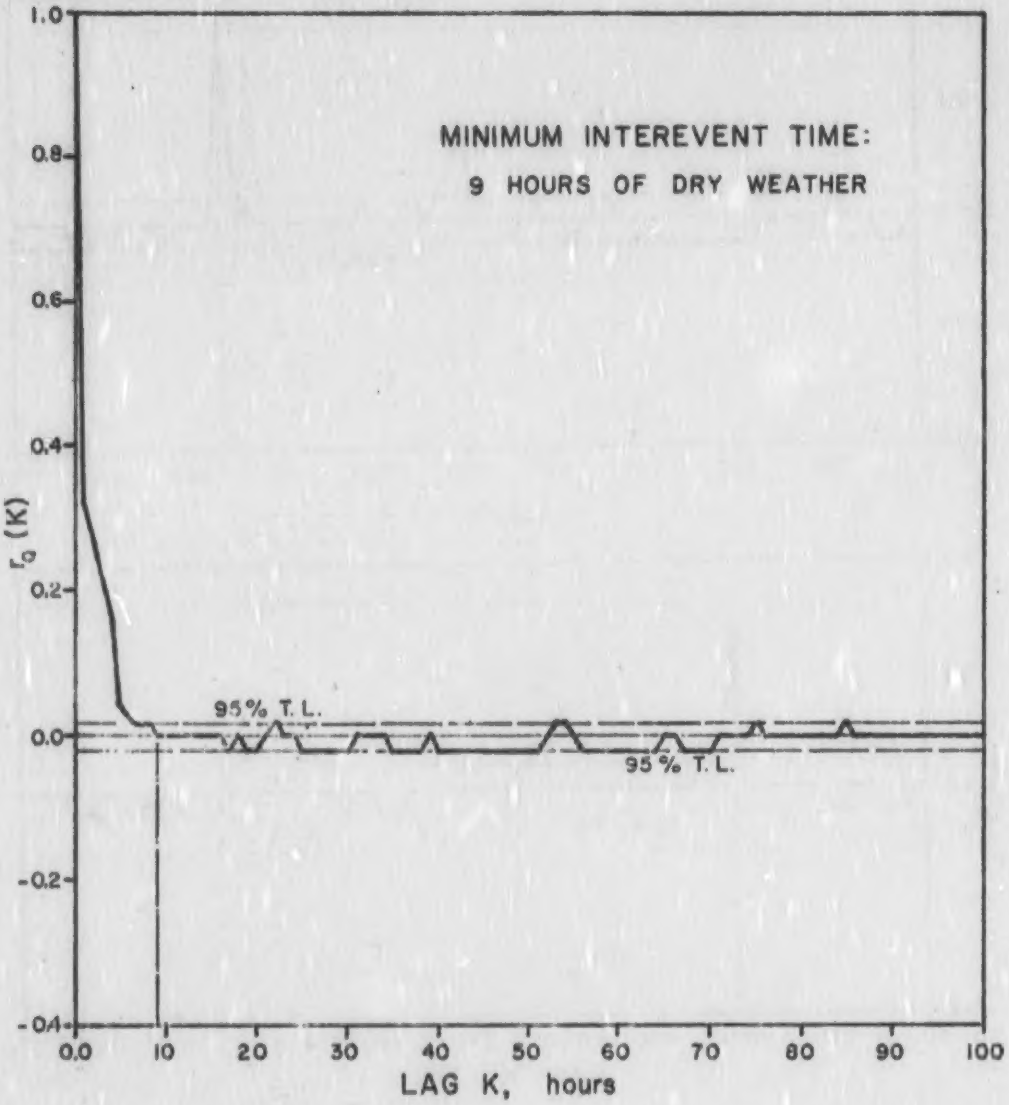


Figure VII-4. Autocorrelation Function of Hourly Urban Runoff for Des Moines, Iowa, 1968.

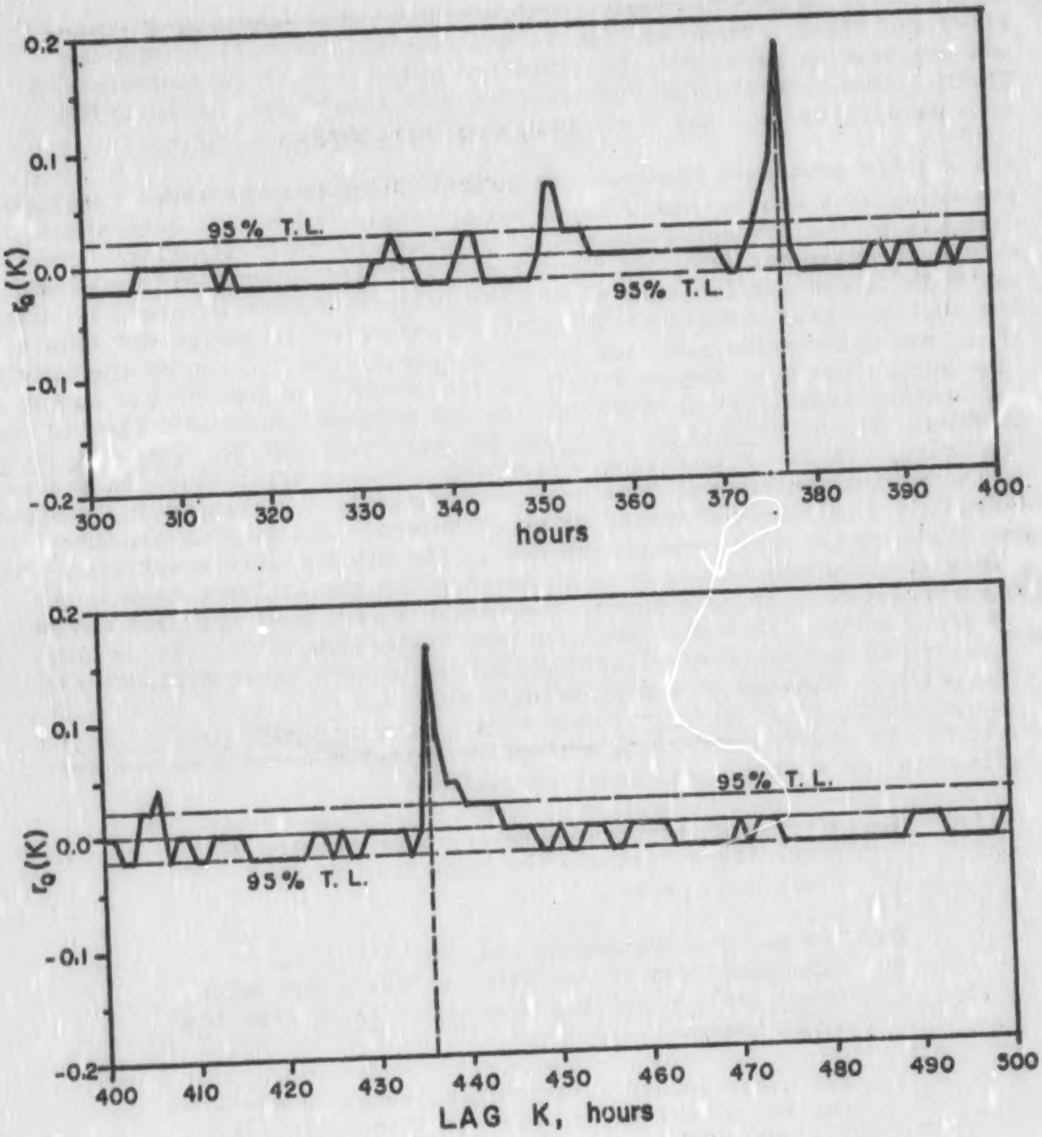


Figure VII-4 (continued). Autocorrelation Function of Hourly Urban Runoff for Des Moines, Iowa, 1968.

Slight differences are observed between the correlograms of Figures VII-3 and VII-4. These are due to the fact that depression storage and evaporation rates must be satisfied before runoff is generated by STORM. Thus, the digital simulation of the runoff process by STORM acts as a filter and has a slight smoothing effect.

The graphic procedure requires the number of dry-weather hours immediately preceding each hourly runoff occurrence. These values are determined directly by the chronological record provided by STORM of all the runoff events it generates from the input rainfall. If a hydrologic model such as STORM is not available, a close approximation may be obtained by assuming that the same numbers of DWH precede the rainfall and runoff events. Thus, the information provided by the precipitation records or the rainfall time series (such as Figure VII-2) is sufficient. A plot of the number of wet-weather events obtained by varying the minimum interevent time is shown in Figure VII-5, Definition of a Wet-Weather Event for Des Moines by Graphic Procedure. It is evident that a time value exists after which an increase in the minimum interevent time does not result in a correspondingly significant reduction in the number of storm events. The graphic procedure selects a period of 8 consecutive DWH as the minimum interevent time. The result is remarkably close to that obtained by the analytic technique, autocorrelation. In some cases, however, the graphical approach may not exhibit a curve with such a well-defined transition point. It is then necessary to apply classical statistical techniques to investigate the sequential properties of the hydrologic series.

Based on the above analyses, a wet-weather event and its duration are defined in the mathematical model as follows:

1. Any runoff occurrence having nine or more DWH preceding it denotes the beginning of the event (see below).

2. The event continues as long as all of the subsequent runoff occurrences have a DWH value immediately preceding them equal to or less than eight hours.

3. The event runoff duration (in hours) is equal to the sum of all the runoff occurrences in (2).

4. The actual event duration (in hours) must be determined by examining the date and hour of the first runoff value and the date and hour of occurrence of the last runoff value within the event.

The hourly urban runoff and associated pollutant loads within each event (including DWF pollutant loads during DWH periods less than nine hours duration) are summed, average conditions are determined, and the model proceeds with the receiving water analysis.

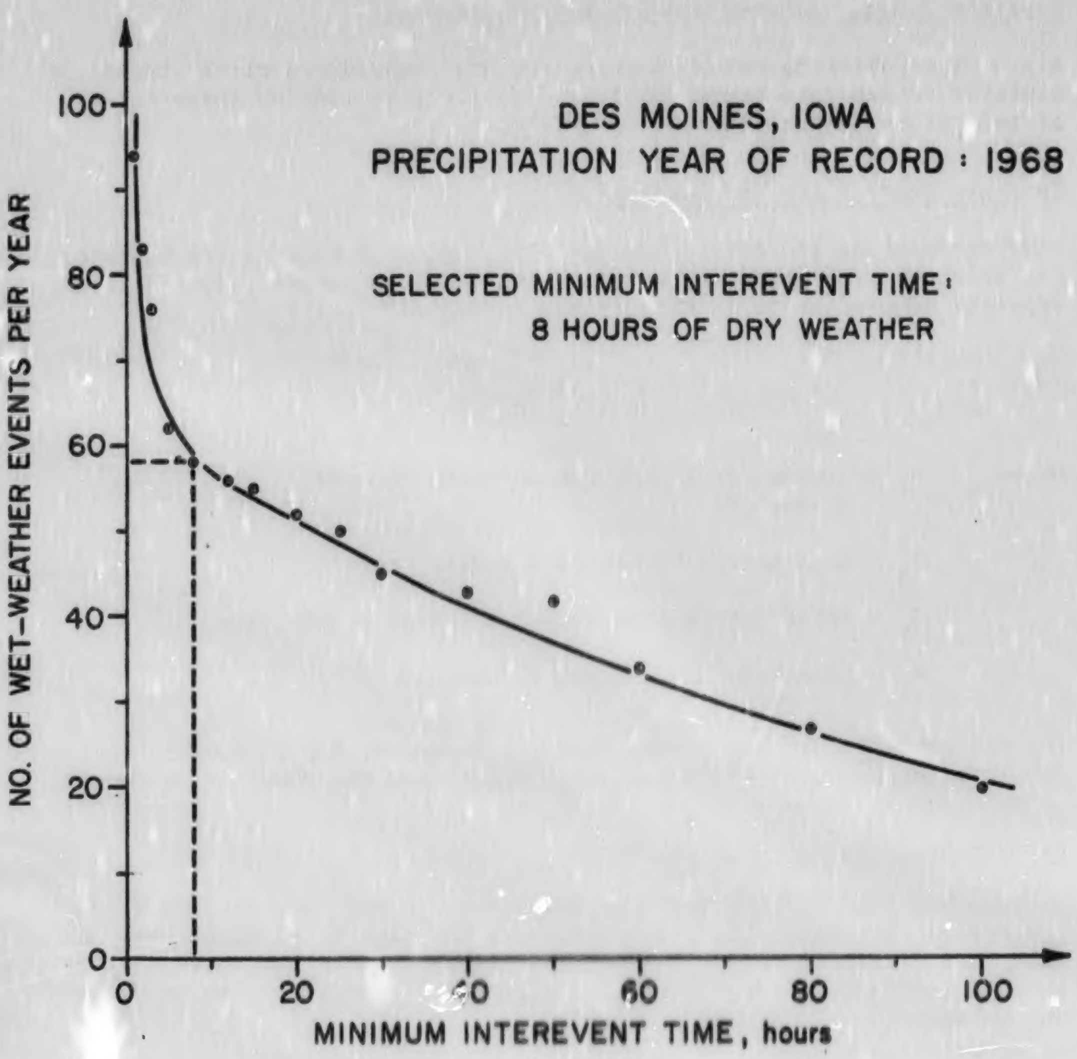


Figure VII-5. Definition of a Wet-Weather Event for Des Moines by Graphic Procedure

Separate Storm, Combined and Dry-Weather Loading

All of the following methodology can be used regardless of the technique employed to generate storm runoff and quality, as long as these values pertain to the entire area being modeled.

Separate Storm Flows and Loadings --

Apportionment of the total flow and BOD loading is made on the basis of the relative area served by separate and combined sewers. Runoff from separate sewered areas is thus (refer to Figure VII-1):

$$Q_s = \frac{A_s}{A_t} Q_t \qquad \text{(VII-7)}$$

where Q_s = stormwater flows from separate sewered areas, cfs,

A_s = area served by separate sewers, acres,

Q_t = total (storm plus combined) urban runoff, cfs, and

A_t = total area of catchment, acres.

The concentration of BOD in separate storm sewers, BOD_s, is simply the hourly value computed by STORM, BOD_t (mg/l), for the total urban runoff.

Dry-Weather Flow and Loadings --

Dry-weather flow and BOD loadings are assumed known from data on point sources in the area. Thus, Q_d represents the flow (cfs) into receiving waters of treated wastewater, and BOD_d represents the BOD concentration at 68°F (20°C) for 5 days, mg/l. The amount of treatment can be varied in the analysis, as stated earlier.

Combined Flows and Loadings --

Dry-weather flow (DWF) is assumed to cause only a negligible increase in flow in a combined sewer during a storm event. However, two factors related to DWF may increase significantly the BOD concentration of the combined sewer storm water:

1. the BOD strength of the municipal sewage with which it mixes; and
2. the BOD exerted by sediment accumulation in each section of the sewer under DWF conditions which is subject to the "first flush" effect induced by the initial runoff.

To incorporate the "first flush" effect, it is assumed that the hourly in-sewer sediment build-up is constant over consecutive dry-weather hours. This assumption is reasonable although it is evident that particle size and specific gravity, depth of flow, and the slope of the conduit are important factors affecting deposition. Data collected by Davis and Borchardt[9] at various combined sewer overflow stations in Des Moines, Iowa, support the first flush theory. BOD and total suspended solids (TSS) concentrations decreased with time with little or no relation to the flow pattern. Furthermore, pollutographs (BOD vs time and TSS vs time) for these stations seem to indicate that the flushing occurs mostly during the first hour of runoff generated by the storm event.

Thus, the mathematical model computes the sewer solids build-up that occurs during the consecutive DWH, then the BOD load contribution from these solids is lumped into the first hour of runoff. The first flush BOD load is given by

$$FF = FFLBS \cdot DWH \cdot A_c \qquad \text{(VII-8)}$$

where FF = first flush BOD load, lbs/hour,

FFLBS = first flush factor, lbs/first flush hour per DWH-acre,

DWH = number of dry-weather hours preceding each runoff event, and

A_c = area served by combined sewers, acres.

The first flush factor, FFLBS, must be determined from

1. the total flow generated by the combined sewer area (including dry-weather flow contribution) during the wet year;
2. the difference in annual average concentration between BOD_c (excluding factor FF) and the measured annual average value; and
3. the total number of DWH for the entire year under study.

An example of this calculation is presented in the application of the model to Des Moines, Iowa.

Apportionment of the total flow on the basis of relative area gives;

$$Q_c = \frac{A_c}{A_t} Q_t \qquad \text{(VII-9)}$$

where Q_c = combined sewer overflow rate, cfs.

Finally, the mixed BOD concentration in the combined sewer, BOD_c (mg/l), is computed by the following expression:

$$BOD_c = \frac{BOD_t \cdot Q_c + BOD_f \cdot Q_d \cdot (A_c/A_t) + FF \cdot C_1}{Q_c + Q_d \cdot (A_c/A_t)} \qquad \text{(VII-10)}$$

where C_1 = factor to convert FF from lb/hr to cfs · mg/l = 4.45.

EFFECT ON STREAMS

Introduction

A broad spectrum of analyses is possible, ranging from simple examination of concentrations at the inflow points to use of detailed receiving water quality simulation models. A simplified mathematical modeling approach is used in which critical deficits and resulting minimum DO concentrations are determined for a large number of waste input combinations, stream conditions, and treatment schemes as indicated in the list of options given earlier. The construction of a detailed receiving water model is not justified for the problem context: to provide information on the relative adequacy of various pollutant control strategies for achieving selected water quality standards. In addition, a much larger data base would have been necessary on river channel geometry, continuous rather than discrete quantity and quality measurements, and other dynamic parameters. Many sophisticated models have outstripped the data base and have consequently severely limited their own applicability.

Some key assumptions, most of them typical of models for interim planning, are made:[13]

1. Temporal steady-state conditions prevail, where all system parameters and inputs are constant with respect to time; however, a relatively short time step (1 hour) is used for simulation.

2. Stream system parameters (such as river flow, velocity, depth, deoxygenation rate, and reaeration rate) are spatially constant along the flow axis throughout each time step.

3. All waste inflows occur at one point on the receiving stream.

4. The effects of various natural biological processes (algal photosynthesis and respiration, benthal stabilization) are incorporated into a background quality which is reflected by DO deficit (if none, by saturation) upstream from the waste inflow point. Any benthic buildup is incorporated into the BOD decay rate.

5. Waste treatment facilities operate at constant efficiencies, independent of hydraulic and organic loadings, for the entire period of simulation.

Initial Conditions

Initial conditions of BOD in the river are defined by equation VII-1. In subsequent equations, the mixed BOD concentration in the river will be denoted by L_o. Thus,

$$L_o \equiv BOD_m \qquad \text{(VII-11)}$$

The assumption that all waste inflows occur at one point is not unreasonable for Des Moines, but in some locations the distribution of inflows along the river may need to be considered. It is important to emphasize that all of the BOD contributors in equation VII-1 represent BOD_5 values. Thus, the mixed BOD concentration in the river, BOD_m, is also in terms of the standard BOD test. The ultimate first-stage (carbonaceous) demand is related to the BOD_5 value by:

$$(L_o)_c = \frac{BOD_5}{1-e^{-5K_1}} \qquad \text{(VII-12)}$$

where $(L_o)_c$ = ultimate first-stage BOD demand, mg/l, and

K_1 = first-order BOD decay rate constant, day^{-1}.

Through verification analysis the value of K_1 was determined to [illegible] 0.7 day^{-1}. Thus, for Des Moines,

$$(L_o)_c = 1.03\ BOD_5 \qquad \text{(VII-13)}$$

and the conversion is unnecessary. Of course, generalizations cannot be made because the decay rate may vary considerably for different river systems.

The other initial condition required is the initial oxygen deficit, D_o. It is assumed that all waste inflows will be at saturation. Thus, the only contribution to the initial deficit will be from the upstream portion of the river. Thus,

$$D_o = \frac{D_u Q_u}{Q_u + Q_d + Q_s + Q_c} \qquad \text{(VII-14)}$$

where D_o = initial DO deficit, mg/l, and

D_u = DO deficit in receiving waters upstream of inflow point, mg/l.

Oxygen Balance of Polluted Streams

Pollutant transport processes in a stream system may be adequately approximated by the one-dimensional version of the classical convective diffusion equation. This partial differential equation is based on the principles of conservation of mass (continuity) and is given by:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left[E\frac{\partial C}{\partial x} - UC\right] \pm \Sigma S \qquad \text{(VII-15)}$$

where C = concentration of water quality parameter (pollutant), M/L^3,

t = time, T,

$-E\frac{\partial C}{\partial x}$ = mass flux due to longitudinal dispersion along the flow axis, the x direction, M/L^2T,

UC = mass flux due to advection by the fluid containing the mass of pollutant, M/L^2T,

S = sources or sinks of the substance C, M/L^3T,

U = flow velocity, L/T, and

E = longitudinal dispersion coefficient, L^2/T.

The equation assumes no diffusion of pollutants through the river boundaries (other than what is included in the source-sink term) and is best suited to predict concentrations relatively far downstream from the point of waste injection. Since critical DO deficits usually occur some distance downstream from the waste source, equation VII-15 is particularly well suited for such predictions.

The main sources of dissolved oxygen in the stream are atmospheric reaeration and oxygen production by photosynthesis. The major sinks include carbonaceous oxygen demand (CBOD), nitrogenous oxygen demand

(NBOD), benthal demand, and respiration of aquatic plants. All stream system parameters are assumed spatially constant along the flow axis, and by substituting the various sources and sinks of DO into equation VII-15 the following expression is obtained:

$$\frac{\partial C}{\partial t} = E\frac{\partial^2 C}{\partial x^2} - U\frac{\partial C}{\partial x} + K_2(C_s - C) \qquad \text{(VII-16)}$$

$$- K_1L - K_nN_n + P - R_e - B$$

where C = concentration of DO in the stream, mg/l

E = longitudinal dispersion coefficient, ft^2/sec,

U = freshwater stream velocity, ft/sec,

K_2 = atmospheric reaeration coefficient, hours^{-1},

C_s = dissolved oxygen saturation, mg/l,

$C_s - C$ = dissolved oxygen deficit, mg/l = D,

K_1 = deoxygenation constant of carbonaceous BOD, hours^{-1},

L = remaining carbonaceous BOD concentration, mg/l,

K_n = oxidation coefficient of nitrogenous BOD, hours^{-1},

N_n = remaining nitrogenous BOD concentration, mg/l,

P = oxygen production rate by algal photosynthesis, mg/l-hour,

R_e = algal respiration rate, mg/l-hour, and

B = benthal demand of bottom deposits, mg/l-hour.

For freshwater streams, the advective flux is significantly larger than the mass flux due to longitudinal dispersion.[13] For steady-state analysis, all system parameters are assumed constant in time. Since it is desired to solve for the DO deficit and

$$\frac{\partial C}{\partial t} = 0; \; E = 0; \; \frac{\partial C}{\partial x} = -\frac{\partial D}{\partial x} \qquad \text{(VII-17)}$$

equation VII-16 reduces to an ordinary differential equation:

$$0 = U\frac{dD}{dx} + K_2D - K_1L - K_nN_n + P - R_e - B. \qquad \text{(VII-18)}$$

A basic assumption of the model, stated earlier, is that the effects of the biological processes ($P - R_e - B$) are incorporated into the measured upstream DO deficit. The production and consumption of oxygen by these processes after waste injection are assumed negligible since no data were available. Although measurements of total organic nitrogen and nitrate-nitrogen for upstream sources are available, modeling of the nitrogenous BOD was not possible because:

1. the amount of organic and ammonia nitrogen present in all wastewater inputs is unknown; and

2. the oxidation coefficient of nitrogenous BOD is also unknown.

By applying the above assumptions and expressing the remaining carbonaceous BOD, L, in terms of the ultimate carbonaceous BOD and its reaction, the governing differential equation for dissolved oxygen deficit is reduced to the expression:

$$0 = U\frac{dD}{dx} + K_2D - K_1L_oe^{-\frac{K_1x}{U}} . \qquad \text{(VII-19)}$$

Critical Deficit and DO Levels

The solution of equation VII-19 constitutes the Streeter-Phelps formulation in which the deficit as a function of time since release is

$$D = \frac{K_1L_o}{K_2 - K_1}(e^{-K_1t} - e^{-K_2t}) + D_oe^{-K_2t} \qquad \text{(VII-20)}$$

where D = DO deficit, mg/l,

K_1 = deoxygenation coefficient, hours^{-1},

K_2 = reaeration coefficient, hours^{-1}, and

t = elapsed time, hours.

The critical (maximum) deficit is found through differentiation to be

$$D_c = \frac{K_1L_o}{K_2}e^{-K_1t_c} \qquad \text{(VII-21)}$$

where D_c = critical (maximum) oxygen deficit, mg/l, and

t_c = elapsed time at which critical deficit occurs, hours.

The value of t_c is given by

$$t_c = \frac{1}{K_1(f-1)} \ln \left\{ f[1 - (f-1)\frac{D_o}{L_o}] \right\} \qquad \text{(VII-22)}$$

where f = self-purification ratio

= K_2/K_1.

The minimum DO level is calculated as

$$C_{min} = C_s - D_c \qquad \text{(VII-23)}$$

where C_{min} = concentration of DO at maximum deficit, mg/l, and

C_s = saturation concentration of DO, mg/l.

The saturation concentration is determined from the regression relationship developed by ASCE,[14]

$$C_s = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \qquad \text{(VII-24)}$$

where T = water temperature, °C.

Values of K_1 and K_2

The deoxygenation coefficient, K_1, represents the loss of DO in the water due to reduction of BOD. A calibrated value of 0.7 day^{-1} is used for this simulation for K_1 at 20°C (68°F). A temperature correction and conversion to $hour^{-1}$ gives:

$$K_1(T) = \frac{1}{24}K_1(20°)1.047^{T-20} \qquad \text{(VII-25)}$$

A variety of formulas exists for prediction of the reaeration coefficient K_2, almost all of which depend upon velocity, U, and depth, H. The equation of Langbein and Durum[15] was chosen because it is most closely related to subsequent procedures used to obtain U and H.

$$K_2 = 2.303 \left[3.3 \frac{U}{H^{1.33}} \right] \qquad \text{(VII-26)}$$

where K_2 = reaeration coefficient at 20°C, day^{-1},

U = stream velocity, ft/sec, and

H = stream depth, ft.

The problem lies in obtaining values of U and H, since the streamflow varies with time. In the absence of measurements, or if the data cannot be obtained in an expedient manner (as in the ensuing application to the Des Moines River), an approximation can be made based on the work of Leopold and Maddock[16] in which they show strong correlations between velocity vs flow and depth vs flow, namely:

$$U = \alpha_1 Q^{\alpha_2} \qquad \text{(VII-27)}$$

$$H = \beta_1 Q^{\beta_2} \qquad \text{(VII-28)}$$

where Q = streamflow, cfs, and

$\alpha_1, \alpha_2, \beta_1, \beta_2$ = regression coefficients.

The model presently utilizes coefficients which were determined for the Kansas River System in Kansas and Nebraska, for which

$$\alpha_1 = 1.60 \qquad \text{(VII-29a)}$$

$$\alpha_2 = 0.03 \qquad \text{(VII-29b)}$$

$$\beta_1 = 0.11 \qquad \text{(VII-29c)}$$

$$\beta_2 = 0.45. \qquad \text{(VII-29d)}$$

When equations VII-27, VII-28 and VII-29 are substituted into VII-26 and conversion is made to units of hour^{-1}, the reaeration coefficient is established as a function of streamflow, Q:

$$K_2 = 2.303 \cdot 4.1435\, Q^{-0.57} \cdot 1.024^{T-20} \qquad \text{(VII-30)}$$

where T = stream temperature, °C, and the last factor represents a temperature correction.

Total Volume of DO Deficit

One reason for determining DO levels for several inflow options is to attempt to establish the relative effect of one source versus another. Unfortunately, the critical deficit, equation VII-21, is nonlinear in terms of the initial BOD, L_o, thus effects cannot be separated directly. One measure of the relative importance is the integral, or summation of the deficit equation VII-20 over all time,

$$\forall = \int_0^\infty D\,dt = \frac{D_o + L_o}{K_2} \qquad \text{(VII-31)}$$

where $\forall$ may be interpreted as the total volume of deficit, with units of mg-hours/l. Values of $\forall$ are displayed by the model for each inflow combination.

Presentation of Results

The impact of urban runoff on the receiving waters is evaluated in terms of violations of potential DO standards, i.e., by the number of times predicted DO levels fall below a specified value. The receiving program, running on an hourly time step for rainy events only, maintains a tabulation of the frequency of DO values within specified intervals, from which the cumulative relative frequency may be plotted, as sketched in Figure VII-6, Hypothetical Results of Simulation. For example, from the figure, the percent of wet-weather events during which a DO standard of, say, 4 mg/l is violated may be readily obtained. Different input options will produce different curves in Figure VII-6 and they may be compared in this manner. Curves are also developed for dry-weather periods and a cumulative annual frequency is obtained.

In addition, the total "volume" of DO deficit, equation VII-31, may be compared for each option. This will give some indication of the relative impact of one option versus another, although the results have no special physical significance.

APPLICATION TO DES MOINES, IOWA

General Description

The City of Des Moines, Iowa is located near the confluence of the Des Moines River and the Raccoon River as shown in Figure VII-7, Map of Des Moines Area. It contains approximately 200,000 people out of the total of 288,000 for the metropolitan area.[9] The mean annual precipitation is 31.27 inches (795 mm) which is approximately equal to the United States average. Based on an extensive sampling program, annual pollutant unit loads upstream from the city were determined (see Table VII-3, Pollutant Unit Loads

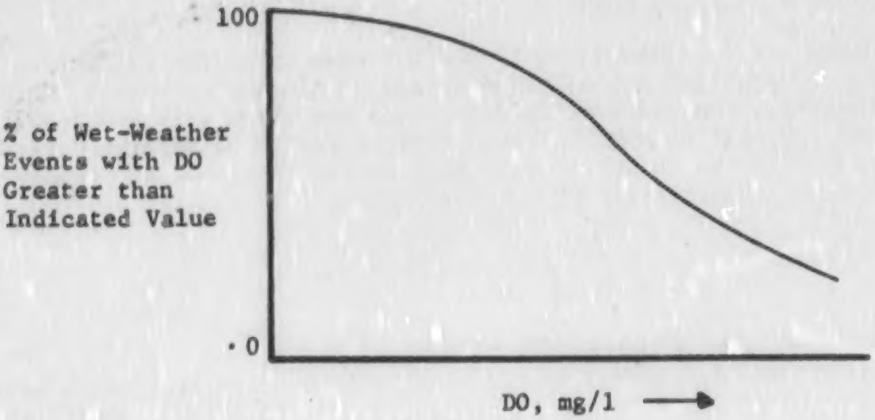


Figure VII-6. Hypothetical Results of Simulation

Table VII-3. POLLUTANT UNIT LOADS FOR DRAINAGE AREA[a] ABOVE DES MOINES, IOWA (Davis and Borchardt, 1974)[9]

	Des Moines River	Raccoon River	Total
Drainage Area, acres (ha)	3,738,000 (1,512,769)	2,202,000 (891,149)	5,940,000 (2,403,918)
Unit Average Annual Runoff, acre-ft/acre (ha-m/ha)	0.42 (0.13)	0.40 (0.12)	0.41 (0.12)
Unit BOD, lbs/acre (kg/ha)	13.40 (15.02)	6.93 (7.77)	11.01 (12.34)
Unit NO_3, lbs/acre (kg/ha)	3.75 (4.20)	3.74 (4.19)	3.75 (4.20)
Unit PO_4, lbs/acre (kg/ha)	0.54 (0.61)	0.42 (0.47)	0.50 (0.56)

[a] On an annual basis.

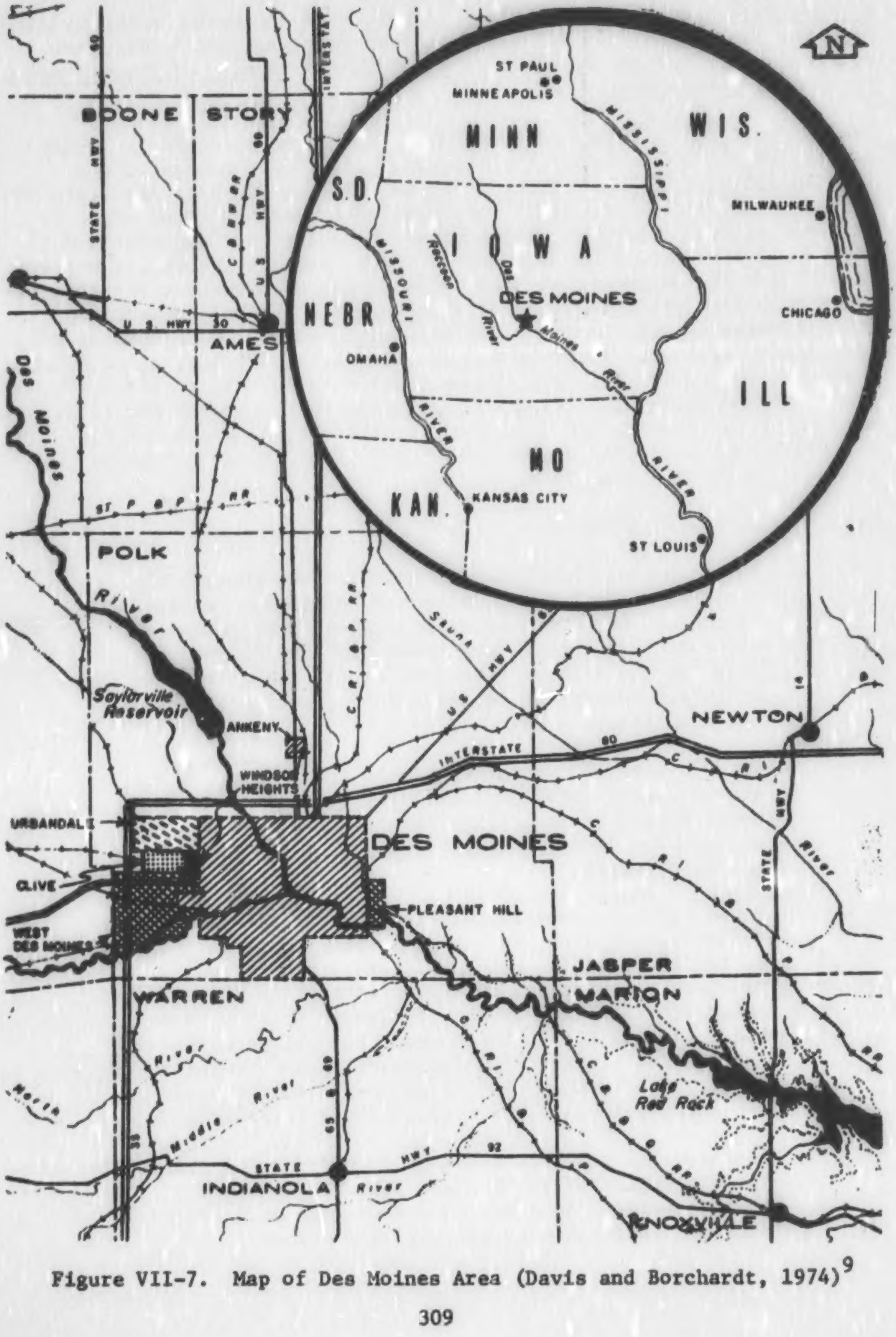

N
ST PAUL
MINNEAPOLIS
MINN
WIS.
S.D.
MILWAUKEE
IOWA
NEBR
DES MOINES
CHICAGO
OMAHA
ILL
MO
KAN.
KANSAS CITY
ST LOUIS
MISSISSIPPI
MISSOURI RIVER
Raccoon River
Des Moines River
BOONE
STORY
AMES
POLK
Saylorville Reservoir
ANKENY
WINDSOR HEIGHTS
URBANDALE
CLIVE
WEST DES MOINES
DES MOINES
PLEASANT HILL
NEWTON
JASPER
MARION
WARREN
Lake Red Rock
INDIANOLA
KNOXVILLE
INTERSTATE 80
U S HWY 30
STATE HWY 92
Skunk River

Figure VII-7. Map of Des Moines Area (Davis and Borchardt, 1974)[9]

for Drainage Area Above Des Moines, Iowa). The estimated annual loading from the urban area's 45,000 acres of separate sewer and 4,000 acres of combined sewer systems is shown in Table VII-4, Summary of Present Annual Metro Area Discharges.

Taking the total upstream drainage area for the Raccoon and Des Moines Rivers, the pollutant contributions are: 65,225,000 pounds of BOD (29,586,000 kg); 22,222,000 pounds of NO_3 (10,080,000 kg); and 2,940,000 pounds of PO_4 (1,334,000 kg). The urban area loadings (when added to upstream values) represent, respectively: 15 percent, 3 percent and 51 percent of the total BOD, NO_3, and PO_4 mass loadings to the Des Moines River below the metropolitan area. The Davis and Borchardt report estimates made from river sampling data taken below Des Moines indicate the following average annual river loadings: 70,000,000 pounds of BOD (31,751,466 kg); 25,400,000 pounds of NO_3 (11,521,250 kg); and 7,950,000 pounds of PO_4 (3,606,059 kg). These figures reveal that: (1) 6,610,000 pounds of BOD (2,998,246 kg) are "lost" in transit through the urban section of the stream, and (2) by contrast 2,474,360 pounds of NO_3 (1,122,351 kg) and 1,917,400 pounds of PO_4 (869,718 kg) are gained in addition to the measured urban sources.

Davis and Borchardt offer some explanations:

> The "sometimes" decrease in organic load through the metro area may be attributable to treatment realized in the low head impoundments at Scott and Center Streets on the Des Moines River and just below Fleur Drive on the Raccoon. To some extent these impoundments may be serving as intermittent sedimentation and stabilization units.
>
> All BOD data, including that used from the two other studies, were obtained from unfiltered samples. However, since the analytical technique was the same for all samples, the relative magnitude of the data should not be affected.
>
> There has been some speculation that treated wastewater effluents may exert an antagonistic or retardant effect on the BOD exertion rate of the receiving stream. If true, this may be due to surfactants or to the expected lower exertion rate of the effluent. In this regard, the decreased BOD in 4 or 5 measurements between R-5 and R-6 is of interest. Increased loads between the summation of R-4 and R-9 versus R-5 are likely due to raw and combined sewage bypassing the intervening area.
>
> Another, and probably the most practical, possibility for the discrepancies is the fact that the data are biological and biochemical in nature and such data do not always provide predictable comparative summations.

Table VII-4. SUMMARY OF PRESENT ANNUAL METRO AREA DISCHARGES[a] (Davis and Borchardt, 1974)[9]

	Days	BOD, lbs (kg)	NO_3, lbs (kg)	O.PO_4, lbs (kg)
Wastewater Treatment Plant Effluent				
Dry-Weather	257	4,060,600 (1,841,857)	400,900 (181,845)	1,737,300 (788,026)
"Wet" Dry-Weather[b]	108[e]	2,246,400 (1,018,950)	237,600 (107,774)	1,036,800 (470,285)
Subtotal	365	6,307,000 (2,860,807)	638,500 (289,619)	2,774,100 (1,258,311)
"Wet" Dry-Weather Overflow[c]	108[e]	2,235,600 (1,014,051)	9,700 (4,400)	263,500 (119,522)
Wet-Weather Combined Sewer Overflows[d]				
2.72 in. (69.1 mm) Rain	1	40,500 (18,370)	240 (109)	6,350 (2,880)
1.50 in. (38.1 mm) Rain	5	101,500 (46,040)	680 (308)	12,200 (5,534)
0.75 in. (19.1 mm) Rain	12	32,500 (14,742)	220 (100)	3,250 (1,474)
0.375 in. (9.5 mm) Rain	18	0	0	0
0.175 in. (4.4 mm) Rain	20	0	0	0
Subtotal	56	174,600 (79,197)	1,140 (517)	21,800 (9,888)

Table VII-4 (continued). SUMMARY OF PRESENT ANNUAL METRO AREA DISCHARGES

	Days	BOD, lbs (kg)	NO_3, lbs (kg)	$O.PO_4$, lbs (kg)
Urban Storm Water Discharges[d]				
2.72 in. (69.1 mm) Rain	1	292,000 (132,449)	6,800 (3,084)	3,900 (1,769)
1.50 in. (38.1 mm) Rain	5	765,000 (346,998)	15,300 (6,940)	9,200 (4,173)
0.75 in. (19.1 mm) Rain	12	966,000 (438,170)	19,300 (8,754)	12,000 (5,443)
0.375 in. (9.5 mm) Rain	18	495,200 (224,619)	9,900 (4,491)	6,200 (2,812)
0.175 in. (4.4 mm) Rain	20	149,800 (67,948)	3,000 (1,361)	1,900 (862)
Subtotal	56	2,683,000 (1,219,256)	54,300 (24,630)	33,200 (15,059)
Total Annual Discharge	365	11,385,100 (5,164,194)	703,640 (319,166)	3,092,600 (1,402,780)

[a] Based on sampling periods from October 1968 to October 1969.

[b] Based on hydraulic capacity of treatment plant and its average effluent BOD during wet-weather periods from May to July 1969.

[c] Refers to sanitary overflow during wet-weather.

[d] Based on annual average rainfall patterns obtained from NOAA.

[e] Includes severe infiltration which prolonged effects of wet weather.

The sampling stations (Numbers 4, 5, 6, 9) are shown in Figure VII-8, Location Map: River Sampling Points. Intervening creeks, such as Beaver Creek, which carries nutrient loads of 2,860,000 pounds of NO_3 per year (1,297,274 kg per year) and 390,000 pounds of PO_4 per year (176,900 kg per year), may be an answer to observed differences in the nitrate loads. However, the phosphate totals are still unbalanced and the cause unresolved.

As stated earlier, the relative importance of a city is expected to increase as the size of the upstream drainage area decreases. To simulate this effect the model application to Des Moines investigates the response of the receiving water when upstream river flow, Q_u, is reduced to various fractions of measured flow. This option and others used for the Des Moines simulations are summarized in Table VII-5, Options Used for Des Moines Simulations. Thus, there is output for $5 \cdot 4 \cdot 3 \cdot 3 = 180$ combinations for each of four different combined area fractions. Conditions particular to Des Moines, Iowa, and the Des Moines River are investigated as well as the response of the receiving stream to hypothetical situations.

Data Sources

The data may be broken into categories describing needs for the runoff simulation. All land use, population density, areas, curb lengths, etc., were obtained from data prepared by APWA for STORM simulations (Volume III). Hourly rainfall values for the year 1968 were obtained from the National Weather Records Center at Asheville, North Carolina. The area served by combined sewers, $A_c = 4{,}000$ acres, is given on p. 2 of the Davis and Borchardt report.[9] Dry-weather flow values are taken from Table 5, p. 52. Receiving water upstream flows, temperatures, BOD and DO levels are taken from pp. 285-308. Total urban runoff (Q_t) and its BOD concentration (BOD_t) are obtained from the STORM simulation on an hourly basis. BOD_s, Q_s, BOD_d, Q_d, BOD_c, BOD_w and Q_w are computed from input data and appropriate mixing equations by the simplified mathematical model described in this section.

The first flush factor, FFLBS, was determined as follows:

$$\text{DWH/year} = 6{,}993 \text{ hour}$$

$$\text{Total flow combined} = 1.55 \times 10^8 \text{ cf/yr} \quad (4.39 \times 10^6 \text{ cu m/yr}).$$

Mixed concentration of storm water (from STORM) plus DWF = BOD_c = 62 mg/l.

The annual average BOD concentration in the combined sewer was measured by Davis and Borchardt[9] to be 72 mg/l.

$$\text{BOD difference} = 10 \text{ mg/l} = 0.0006243 \text{ lbs/ft}^3$$

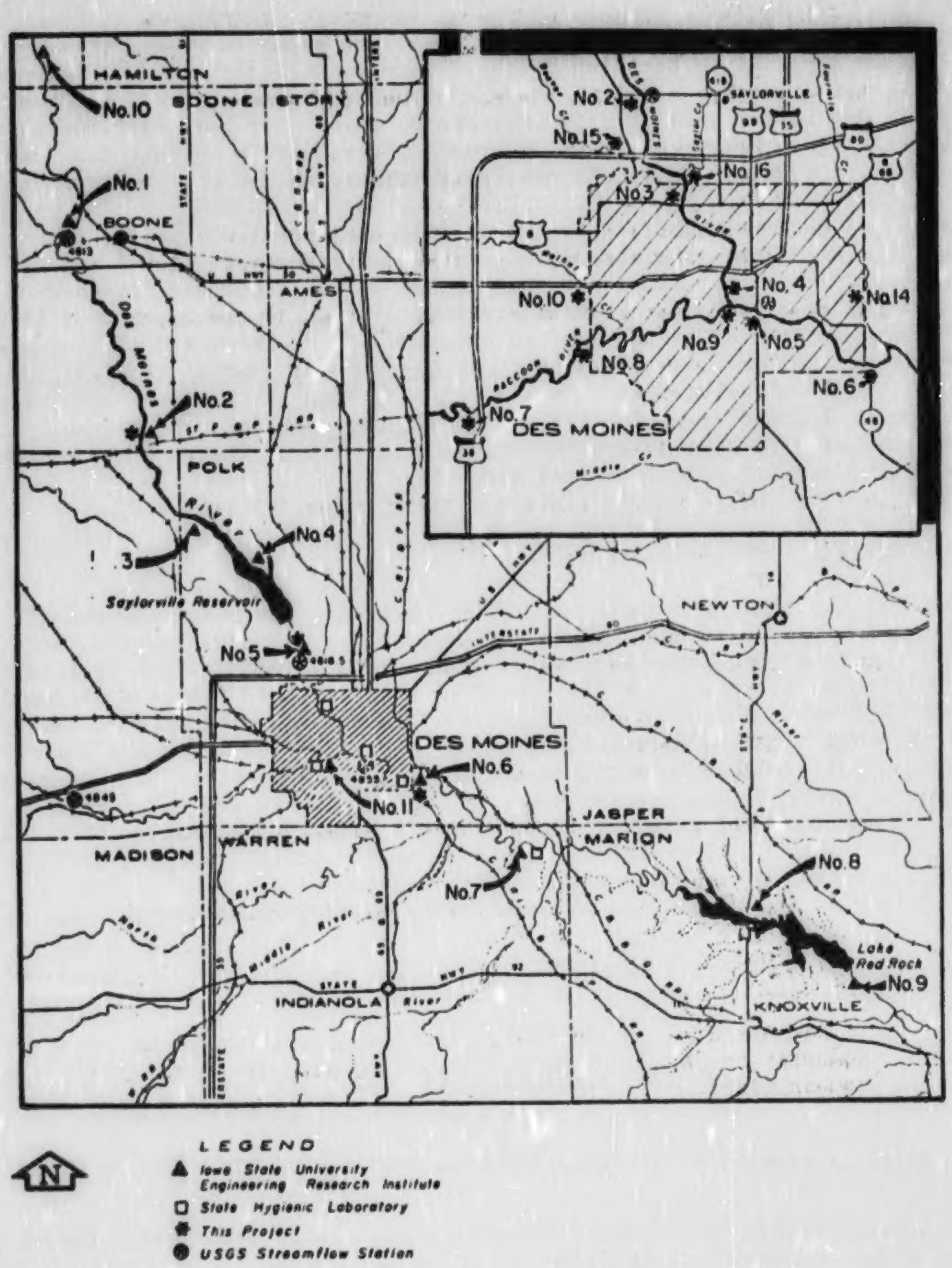

HAMILTON
No.10
BOONE
STORY
No.1
BOONE
AMES
Des Moines
No.2
POLK
River
No.4
3
Saylorville Reservoir
No.5
NEWTON
DES MOINES
No.6
No.11
JASPER
MARION
MADISON
WARREN
No.7
No.8
Lake Red Rock
No.9
INDIANOLA
KNOXVILLE
No 2
SAYLORVILLE
No.15
No.16
No.3
No.10
No. 4
No.14
No.9
No.5
No.8
No.6
No.7
DES MOINES
N
LEGEND
Iowa State University Engineering Research Institute
State Hygienic Laboratory
This Project
USGS Streamflow Station

Figure VII-8. Location Map: River Sampling Points (Davis and Borchardt, 1974)[9]

TABLE VII-5. OPTIONS USED FOR DES MOINES SIMULATIONS

The following five inflow combinations (M)[a] are used:

1. River flow + DWF
2. River flow + DWF + separate flow
3. River flow + DWF + combined flow
4. River flow + separate flow + combined flow
5. River flow + DWF + separate flow + combined flow

and the following four DWF treatment rates (J) are used:

1. 0% (no treatment)
2. 30% (primary)
3. 85% (secondary)
4. 95% (tertiary)

and the following three WWF treatment rates (L) are used:

1. 0% (no treatment)
2. 25%
3. 75%

and the following three river flows (K) are used:

1. 0% of measured flow
2. 25% of measured flow
3. 100% of measured flow

and the fraction of combined area is varied four times:

1. 0% of total urban area
2. 8.16% of total urban area (existing conditions)
3. 50% of total urban area
4. 100% of total urban area

---

[a] Parameters J, K, L and M were used as subscripts in the computer output and serve to aid in labeling the various combinations.

$$\text{BOD load} = (0.0006243\ \text{lbs/cf})(1.55\text{x}10^{8}\ \text{cf/yr})$$

$$= 96{,}766.50\ \text{lbs/yr}\ (43{,}892.50\ \text{kg/yr})$$
that can be attributed to first flush effects

$$\text{FFLBS} = \frac{96{,}766.50\ \text{lbs/yr}}{(6993\ \text{DWH/yr})(4000\ \text{acres})}$$

$$= 0.0035\ \text{lbs/DWH-acre}$$

$$= 0.0039\ \text{kg/DWH-ha.}$$

This factor, as demonstrated earlier, is then used in equation VII-8 to estimate the first flush BOD load, FF, during the first hour of runoff generated by each storm event.

Special Problems

During the model application to Des Moines, various problems were encountered revolving around the critical deficit (D_c) and critical time (t_c) equations, equations VII-21 and VII-22, respectively. Due to the large number of conditions being simulated, including dry watercourses in which the waste inputs constituted the only flow, situations were encountered in which:

1. the deficit load ratio, R_o, was undefined

$$R_o = \frac{D_o}{L_o} \qquad \text{(VII-32)}$$

because both D_o and L_o were equal to zero;

2. the self-purification ratio, f, was equal to one, causing equation VII-22 to be undefined; and

3. values of R_o were such that negative values of t_c were obtained.

Mathematical analysis led to the incorporation of certain modifications and safeguards. Thus, equations VII-21 and VII-22 were defined only for:

1. $f \neq 1$,

2. $L_o \neq 0$, and

3. $0 \leq R_o \leq 1/f$.

Otherwise, in order, if

1. $f = 1$, then

$$D_c = L_o e^{R_o - 1} \qquad \text{(VII-33)}$$

2. $f \neq 1$, $L_o = 0$, then

$$D_c = D_o \qquad \text{(VII-34)}$$

3. $f \neq 1$, $L_o = 0$, $R_o > 1/f$, then

$$D_c = D_o. \qquad \text{(VII-35)}$$

These equations, obtained by taking limits, are not particular to Des Moines and are applicable to any receiving stream.[17]

Verification Analysis

An important part of the total effort required to develop a mathematical model of water quality in a stream is devoted to verification and improvement of model accuracy. The verification procedure recommended for steady-state water quality models includes:

1. examination of model output using preliminary coefficients on a diverse set of data (different waste loads and temperatures under conditions of high and low flow, and variable initial stream quality);
2. assessment of the closeness of fit of observed field data to computed values;
3. adjustment of the model coefficients until the desired accuracy is obtained; and
4. achievement of a mathematical abstraction that reasonably reproduces observed stream response and establishes the necessary validity for planning purposes.

The verification procedure was preceded by calibration of the urban runoff BOD_5 loading rates for Des Moines, Iowa, as computed by STORM. The dust and dirt surface loading factors were adjusted to obtain an annual average BOD_5 concentration of 53 mg/l for urban stormwater runoff. The above concentration was the average value determined by the field monitoring program in the separate sewer system.[9] The developed mathematical model, as discussed in the methodology, simulates the mixing of stormwater runoff and sanitary sewage in the combined sewer system. The annual average BOD_5 concentration of combined sewer overflows was computed to be 75 mg/l, including the effects of first flush. The average value determined by the field monitoring program in the combined sewer system was determined to be 72 mg/l.[9]

The carbonaceous BOD reaction coefficient, K_1, was refined during the verification process to a final value of 0.70 day^{-1} (at 20°C). The model, of course, converts to units of $hour^{-1}$ and adjusts for temperature through equation VII-25. The atmospheric reaeration coefficient, K_2, is calculated internally as a function of streamflow and temperature by equation VII-30; therefore, no adjustment was necessary. Measured and computed values of DO at a point 5.6 miles (9.0 km) downstream from the confluence of the Raccoon and Des Moines Rivers are compared in Figure VII-9, Application to Des Moines, Iowa. Correlation between the calculated and observed profiles is quite good. The point corresponds to sampling location no. 6 as shown previously in Figure VII-8.

Included in Figure VII-9 are rainfall and average total river flow values for each wet-weather event (as defined in Figure VII-4). Differences between measured and computed DO concentrations may be attributed to such factors as: (1) the time of day during which the sample was taken; (2) the lag time between sampling and laboratory analysis and the temperature variations in the receiving water during the day; and (3) a lack of data on photosynthesis, algal respiration, and benthic demand. The time scale in days represents the wet year beginning on March 8 and ending December 30, 1968. Again, it should be reemphasized that these DO values are not the minimum DO's resulting from maximum deficits. The maximum deficits occur much further downstream (10 - 30 miles or 16 - 48 km) and water quality standards are violated much more frequently.

Further verification of the model can be achieved by simulating the stream response to hydrologic and waste inputs for, say, the year 1969. However, such a time-consuming task was not deemed justifiable in view of the accuracy already obtained and the study objectives.

Results

Based on NOAA records (Asheville, North Carolina), the total precipitation that fell over Des Moines, Iowa, during 1968 was 27.59 inches (701 mm). STORM computed a total runoff of 10.28 inches (261 mm) over a watershed area of 49,000 acres (19,600 ha), for an overall urban area runoff coefficient of 0.37. There were 65 days in the year during which rainfall was recorded, from which 58 wet-weather events were defined. The results are presented in the form of minimum DO frequency curves for the wet-weather and dry-weather periods throughout the calendar year. The reader is referred again to Table VII-5 for a review of the multitude of options modeled in the Des Moines application.

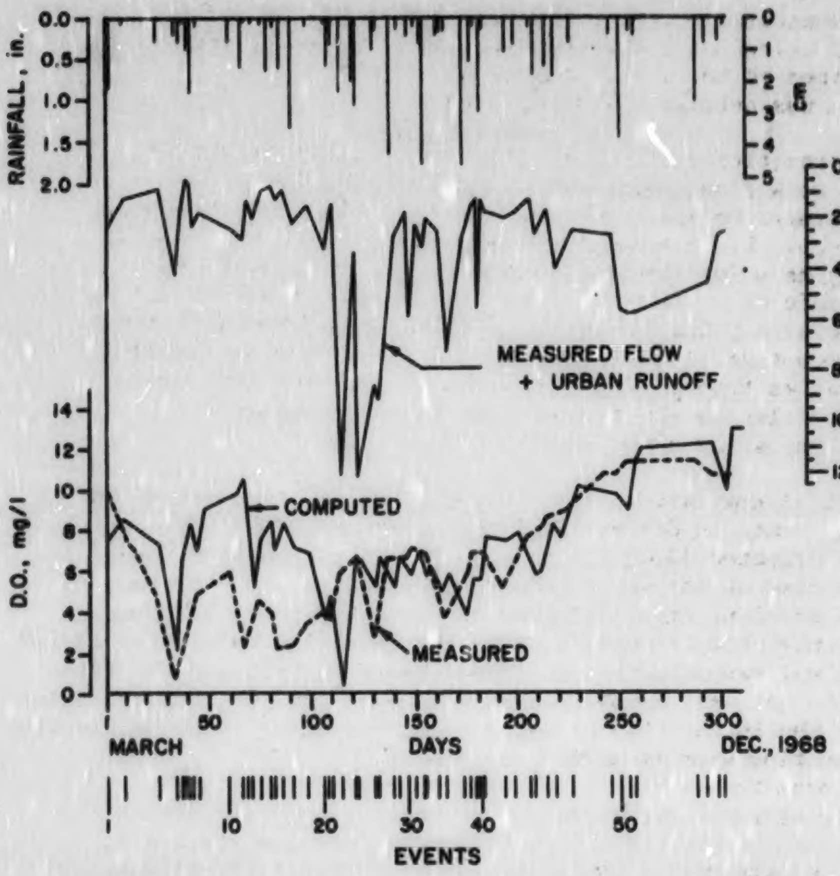


Figure VII-9. Application to Des Moines, Iowa. Measured and computed values of DO at 5.6 mi (9.0 km) downstream from confluence of Raccoon and Des Moines Rivers.

It is appropriate to examine first the model estimates of DO concentration in the Des Moines River for conditions assumed to exist in 1968 during periods of urban runoff:

1. combination M = 5, all waste inputs;
2. secondary treatment (85 percent BOD removal) of DWF, J = 2;
3. no stormwater treatment, L = 1;
4. river flow 100 percent of measured flow, K = 3, and
5. the fraction of combined area is 8.16 percent of the total urban area.

Figure VII-10, Minimum DO Frequency Curves for Existing Conditions in the Des Moines River, illustrates all waste inflow combinations. The curves indicate clearly that all combinations including a substantial amount of wet-weather flow (WWF) result in a drastic decrease in river minimum DO concentrations. For example, 42 percent of all the wet-weather events throughout the year produced conditions in the receiving water that caused minimum DO levels below 4.0 mg/l. Combined sewers contributed WWF from only 8 percent of the total urban area modeled, yet the BOD_c concentration was sufficiently high to inflict an appreciable reduction in DO levels when compared to DWF sources during periods of runoff.

Figures VII-11 through VII-15, Minimum DO Frequency Curves, present the results obtained by considering all waste inputs (combination M = 5, Table VII-5) while varying the other parameters. Figure VII-11 displays the minimum DO frequency curves obtained by varying the percent of the total urban area served by combined sewers. There is a substantial, but not drastic, decrease in water quality when the extreme conditions are compared: an area served only by separate sewers (0 percent combined) versus an area served exclusively by combined sewers. The curves support the theory that total separation of sewers is not the answer to the control of urban runoff pollution. The curves in this figure all represent secondary treatment of DWF, no urban runoff treatment, and full river flow.

Figure VII-12 shows the relative effect of urban stormwater runoff in the upstream portions of the drainage basin. As explained earlier, this effect is modeled by reducing upstream river flow to three different fractions of its actual measured value. DWF is given secondary treatment (85 percent BOD removal), while WWF is untreated. Thus, the only flow in the river consists of DWF and urban runoff when modeling discharge into a dry river bed (K = 1, Table VII-5). Variation of upstream river flow does not reveal large differences in receiving water quality, as might be expected, because of the relatively large volumes of stormwater runoff discharged by the urban area into the river:

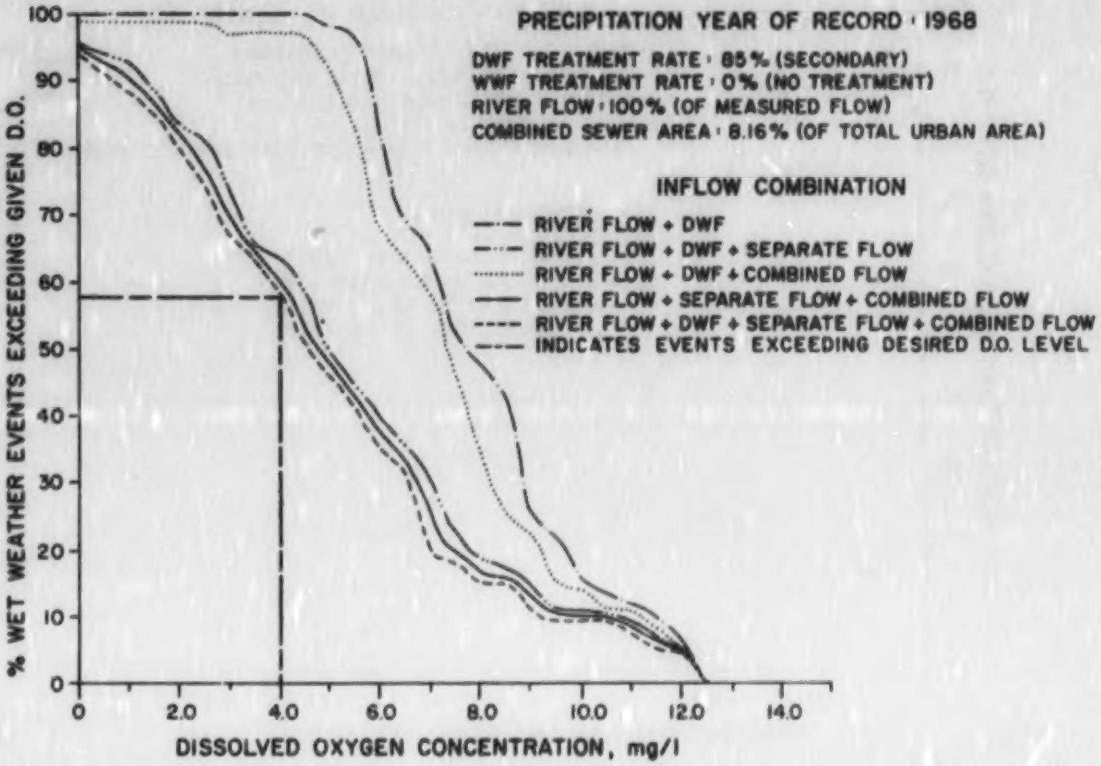


Figure VII-10. Minimum DO Frequency Curves for Existing Conditions in the Des Moines River

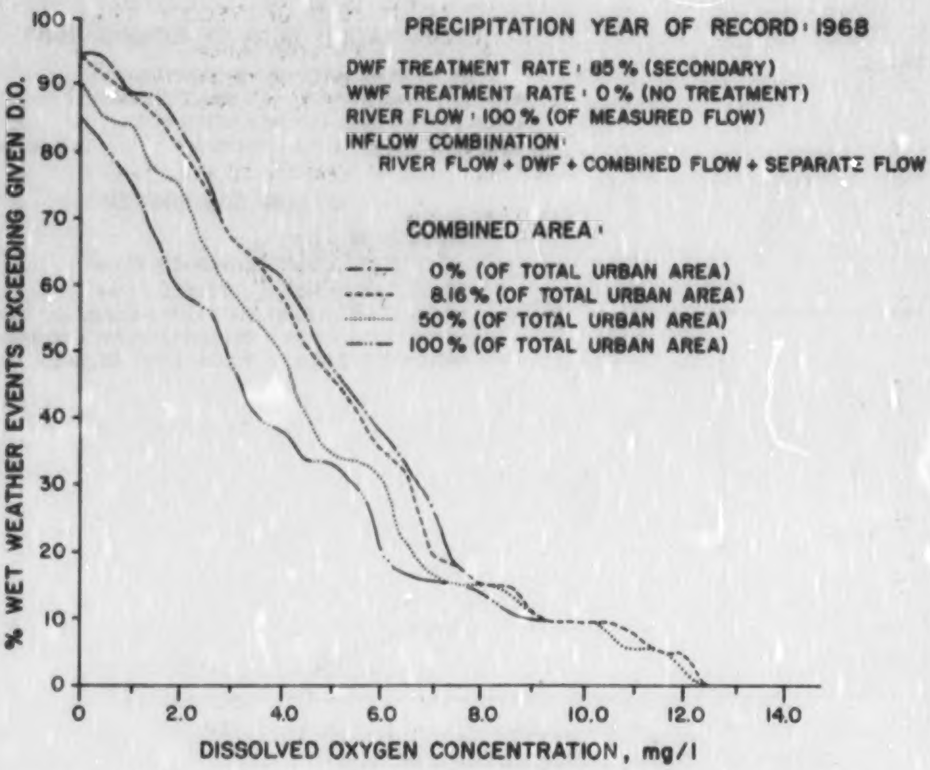


Figure VII-11. Minimum DO Frequency Curves for Varied Percent of Combined Sewer Area

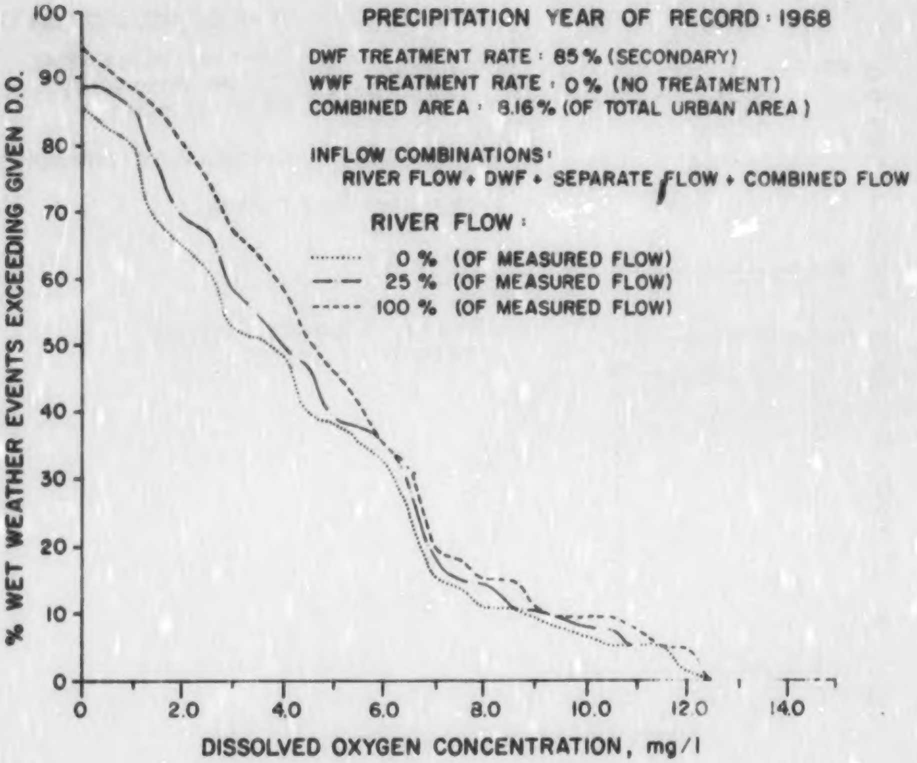


Figure VII-12. Minimum DO Frequency Curves for Varied Percent of Actual Measured Upstream River Flow

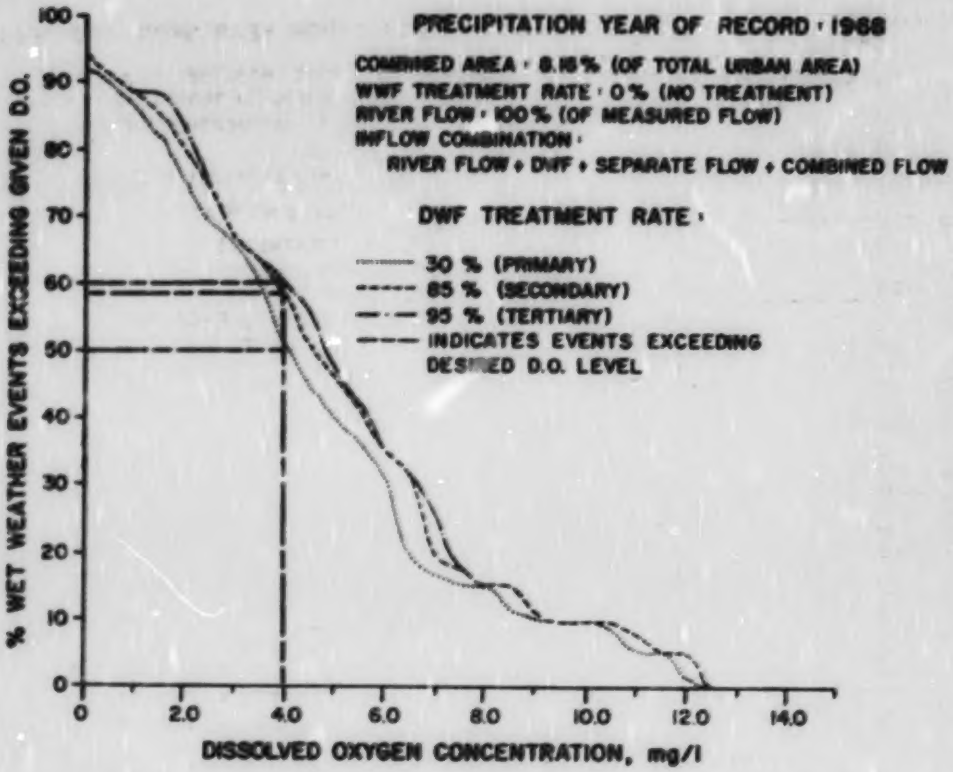


Figure VII-13. Minimum DO Frequency Curves for Varied DWF Treatment

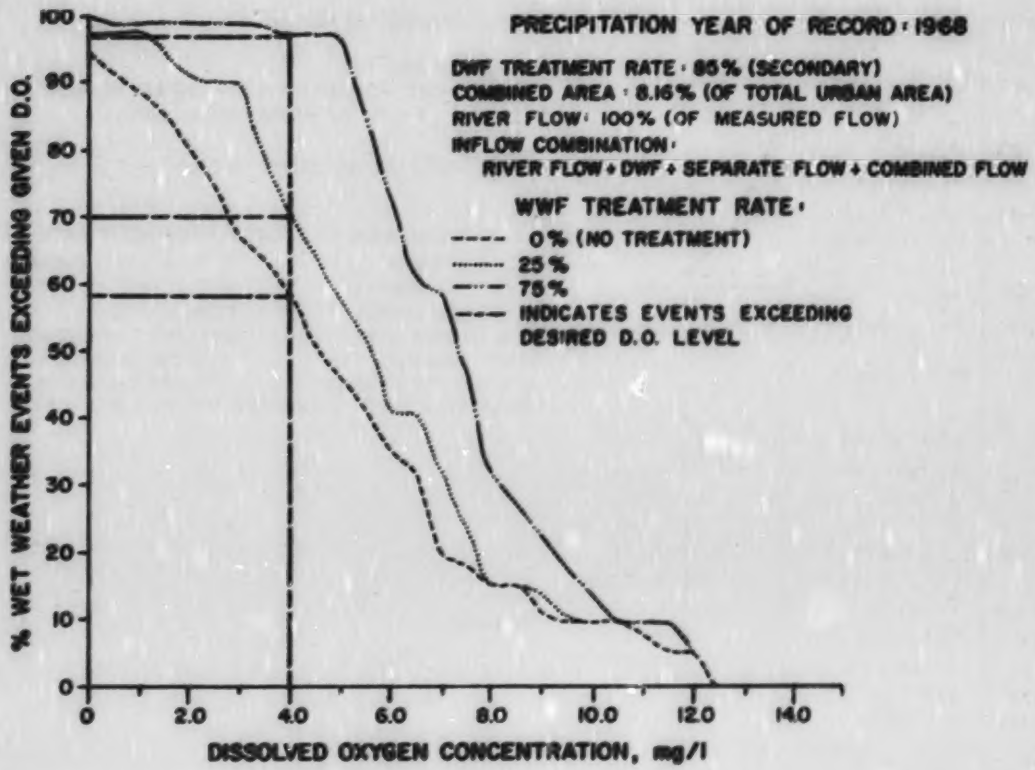


Figure VII-14. Minimum DO Frequency Curves for Varied WWF Treatment

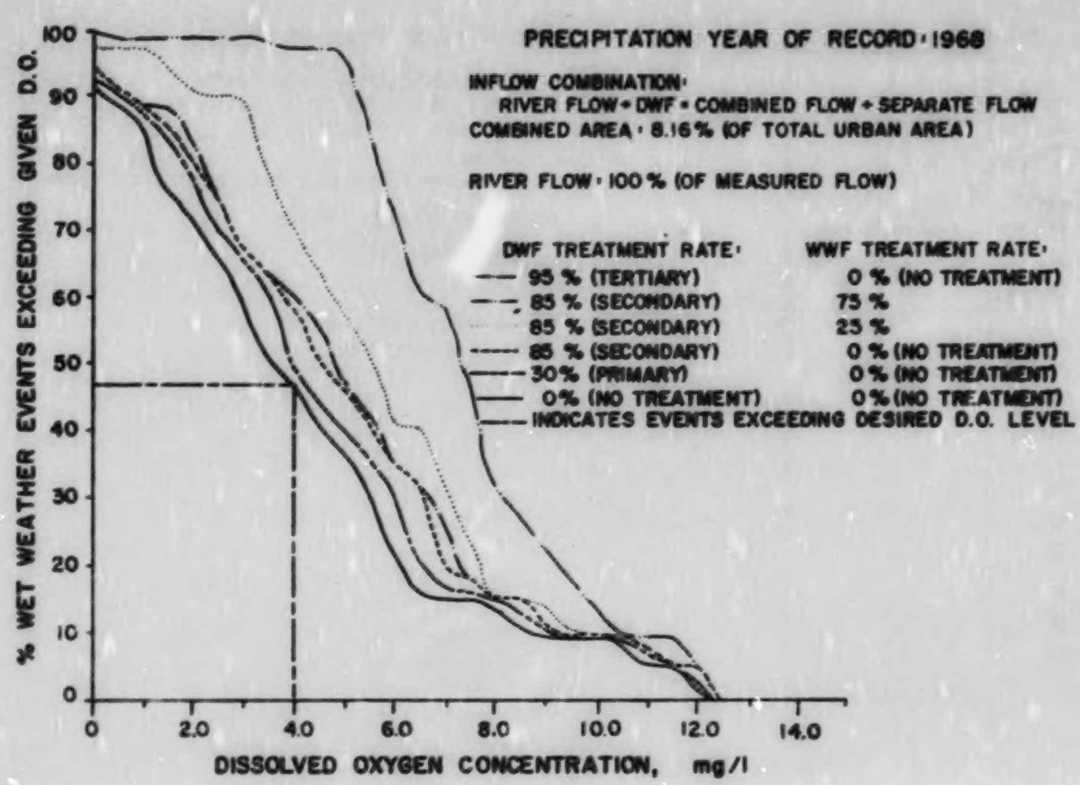


Figure VII-15. Minimum DO Frequency Curves for Varied Treatment Alternatives

1. for all of the precipitation events defined by the model, upstream river flow was on the average 50 percent of the total river flow; and

2. this percentage ranged from as low as 6 percent to as high as 97 percent of total river flow.

For the Des Moines application, and the particular rainfall year selected (1968), urban runoff seems to be the key factor in receiving water critical DO levels. However, an urban area located very far upstream in a river basin would have a more detrimental impact on water quality downstream from the urban area than if the same urban area was located on a higher order stream within the network.

Figure VII-13 shows the effect of varying the degree of treatment of DWF while holding the other parameters constant. It can be inferred that there is no significant improvement of stream water quality (DO) by upgrading DWF treatment from secondary to tertiary during periods of wet weather. However, it is clear that the improvement in minimum DO levels by upgrading DWF treatment from primary to secondary is probably worthwhile: 7 percent more wet-weather events would exceed a DO value of 4.0 mg/l. Examination of Figure VII-14 reveals that critical DO levels are improved appreciably with 25 percent treatment of WWF and markedly with 75 percent treatment of WWF, while providing secondary treatment of DWF. The minimum DO frequency curves in Figure VII-15 compare four treatment alternatives to reduce water pollution during periods of urban runoff:

1. 95 percent treatment of DWF and no treatment of urban runoff,

2. 85 percent treatment of DWF and 25 percent treatment (BOD removal) of WWF,

3. 85 percent treatment of DWF and 75 percent treatment of WWF, and

4. 85 percent treatment of DWF and no treatment or urban runoff.

The zero treatment and primary treatment curves are also shown for comparison, but are not considered acceptable alternatives. It appears that options 1 and 4 above result in comparable critical DO levels in the receiving stream. However, options 2 and 3 result in much more improved critical DO levels. An economic evaluation of these treatment alternatives, on an annual basis, is presented in a later subsection.

It is now appropriate to examine the results of applying the model to periods throughout the year during which no urban runoff was produced. Dry weather was experienced for approximately 300 days throughout 1968. The model was applied to these periods using a daily time step. This modification is certainly justified since conditions are more truly steady-state than during periods of precipitation and subsequent runoff: for example, waste loadings (DWF treatment plant effluent) and river flow do not vary as much during the day. For the dry-weather simulation period, upstream river flow was on the average 94 percent of total river flow, ranging from 82 percent to 99.6 percent. The results are shown in Figure VII-16, Dry-Weather Minimum DO Frequency Curves for Varied DWF Treatment Alternatives. A remarkable 97 percent of the dry-weather days exceed a minimum DO concentration of 4.0 mg/l. Upgrading of DWF treatment becomes meaningful only if stream DO standards are set higher than 4.0 mg/l. From Table VII-3, it is clear that the Des Moines River in particular carries a high BOD load upstream of the Des Moines urban area. This explains why, even during dry-weather periods only, a significant increase in the DWF treatment rate does not result in a corresponding increase in the critical DO levels, as shown in Figure VII-16.

To maintain the proper perspective, it is desirable to view the effects of urban runoff on an annual basis, not just during periods of wet weather. The frequency curves shown in Figures VII-15 and VII-16 are combined by weighting on the basis of the number of rainfall days and dry-weather days in the year. The composite totals are presented in Figure VII-17, Annual Minimum DO Frequency Curves. For example, a given stream standard of 4.0 mg/l is exceeded 90 percent of the time for existing conditions in Des Moines, Iowa, throughout the year 1968. A significant amount of treatment (75% BOD removal) of WWF in addition to secondary treatment of DWF results in critical DO levels such that the same stream standard is exceeded 97 percent of the days in the year. Annual DO duration curves tend to mask the impact of shock loads of organic pollutants discharged during periods of urban runoff. A few extended violations of stream DO standards may cause anaerobic conditions resulting in fish kills and proliferation of undesirable microorganisms.

The integral of the DO deficit equation over all time, equation VII-31, has been suggested as a measure of the relative effect of one waste source versus another. Denoted as Ꝟ, the volume of DO deficit, this parameter is computed for each treatment option during both wet- and dry-weather periods. The average values obtained are given in Table VII-6, Volume of DO Deficit. The results indicate the same ranking of the treatment alternatives as suggested by the curves in Figure VII-17, from a water quality viewpoint. This implies that the integrated DO deficit, Ꝟ, may provide a simple method of comparing the impact upon receiving waters of alternative input configurations. However, interpretation of the numerical value of Ꝟ, in an absolute sense, remains ambiguous.

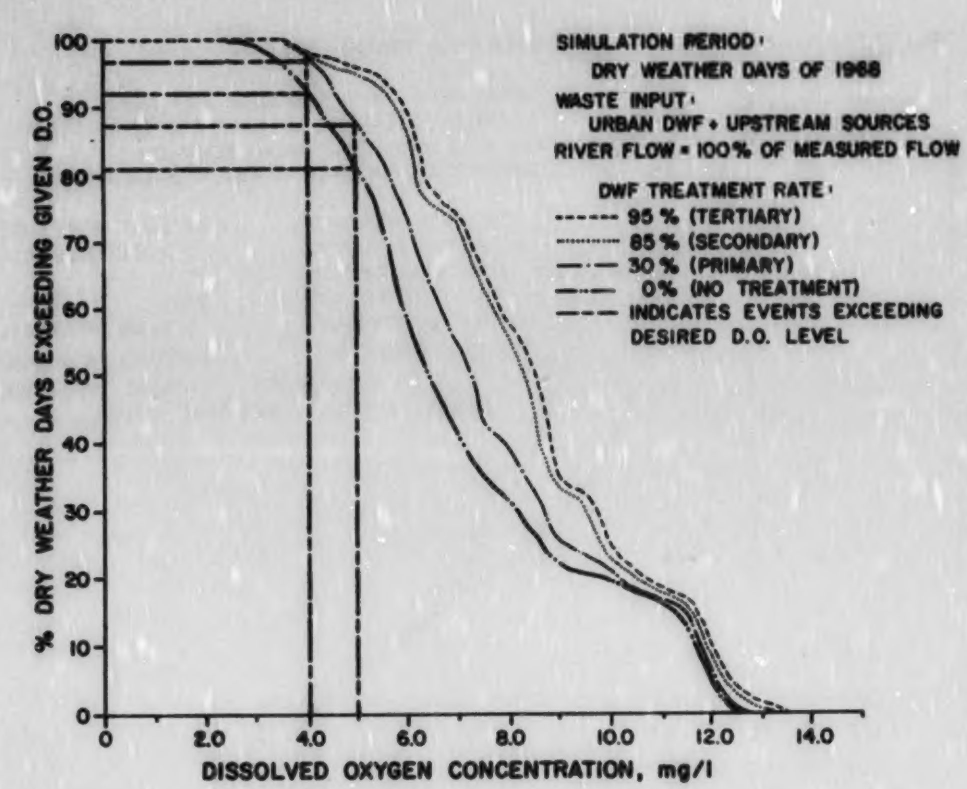


Figure VII-16. Dry-Weather Minimum DO Frequency Curves for Varied DWF Treatment Alternatives

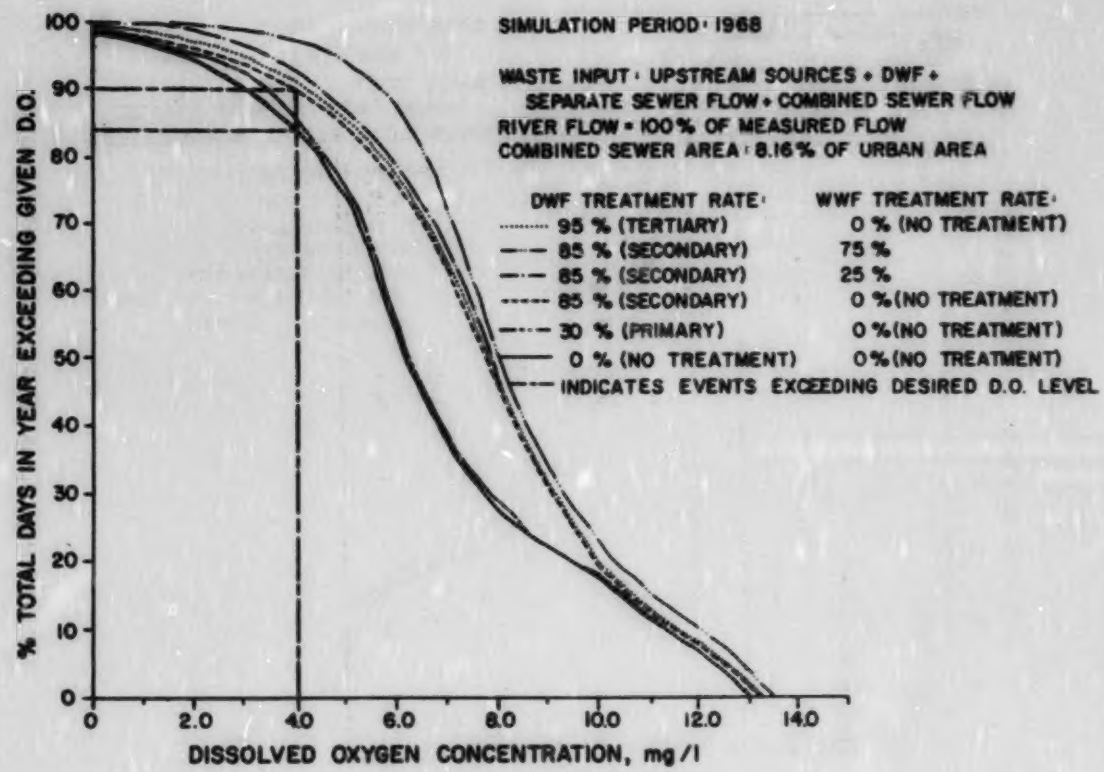


Figure VII-17. Annual Minimum DO Frequency Curves

Table VII-6. VOLUME OF DO DEFICIT[a]

Option	DWF Treatment Rate (% BOD Removal)	WWF Treatment Rate (% BOD Removal)	Average Ψ for Wet Periods (mg-day/l)	Average Ψ for Dry Periods[c] (mg-day/l)	Average Ψ Year (mg-day/l)
1	95 (Tertiary)	0 (No Treatment)	31.5	6.3	10.8
2	85 (Secondary)	75 (Biological, Physical, Chemical)	12.6	7.3	8.3
3	85 (Secondary)	25 (Physical)	25.6	7.3	10.6
4[b]	85 (Secondary)	0 (No Treatment)	32.1	7.3	11.7
5	30 (Primary)	0 (No Treatment)	35.5	12.8	16.8
6	0 (No Treatment)	0 (No Treatment)	37.3	16.0	19.8

---

[a] $\Psi = \frac{D_o + L_o}{K_2}$

[b] Existing conditions in Des Moines, Iowa.

[c] Values correspond to DWF treatment rate only.

ECONOMIC EVALUATION OF TREATMENT ALTERNATIVES

Alternatives

Two major alternatives to existing conditions are considered in this section:

1. upgrading the existing DWF treatment facility from a high-rate trickling filter plant to a tertiary treatment process, or

2. providing two separate levels of urban stormwater runoff control

    i. 25 percent BOD removal, or
    ii. 75 percent BOD removal,

    while maintaining existing DWF removal efficiencies.

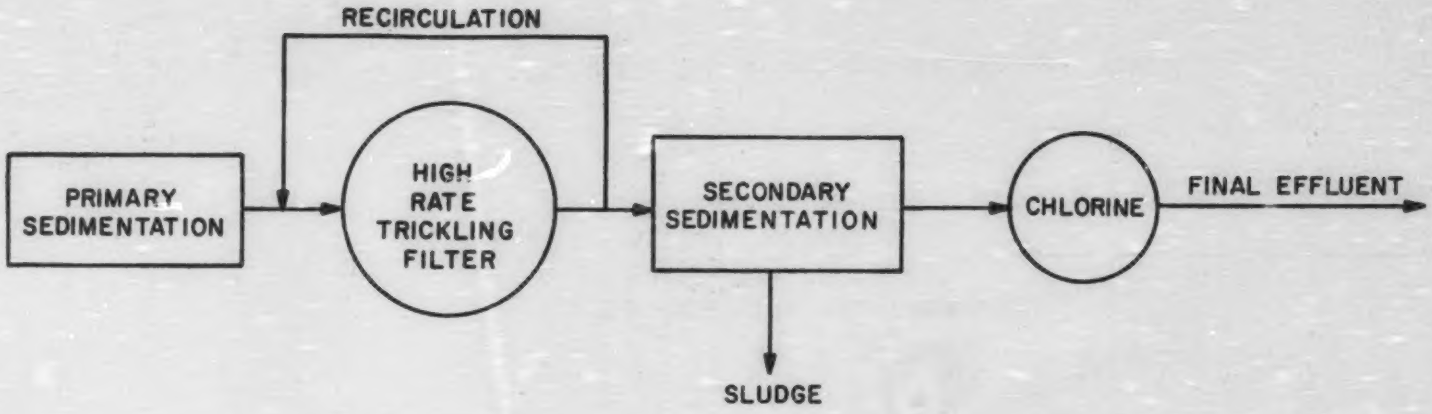
Upgrading DWF Treatment

To achieve a tertiary treatment configuration, the Des Moines DWF treatment facility must undergo an intermediate-stage modification to activated sludge. A simplified profile of the existing DWF treatment plant and its characteristics is presented in Figure VII-18, Existing DWF Process Profile. When an activated sludge unit is added, the trickling filter acts as a roughing filter. The capital costs of this intermediate-stage upgrading are evaluated separately and must be added later to the capital costs associated with a tertiary treatment capability. A profile of the trickling filtration/activated sludge system is shown in Figure VII-19, Trickling Filtration/Activated Sludge System. In 1975 dollars (ENR 2200), for a design flow of 35.3 mgd (134,000 cu m/day), the intermediate-stage capital costs are approximately:[18]

Aeration Tank(s)	$1,560,026
Sludge Recirculation	574,746
Clarifier Modifications	88,000
Total	$2,222,772

These costs do not include engineering design, bonding, and construction supervision.

The unit processes added to achieve tertiary treatment (95 percent BOD removal or better) are shown in Figure VII-20, Added Tertiary Treatment Unit Processes. It is assumed that disposal of chemical sludge is by incineration. Cost figures were obtained from a report by Battelle-Pacific


RECIRCULATION
PRIMARY SEDIMENTATION
HIGH RATE TRICKLING FILTER
SECONDARY SEDIMENTATION
CHLORINE
FINAL EFFLUENT
SLUDGE

DESIGN FLOW: 35.3 MGD

POP. SERVED: 247,920

BOD INFLUENT: 325 mg/l

BOD EFFLUENT: 49 mg/l

% BOD REMOVAL: 85

Figure VII-18. Existing DWF Process Profile

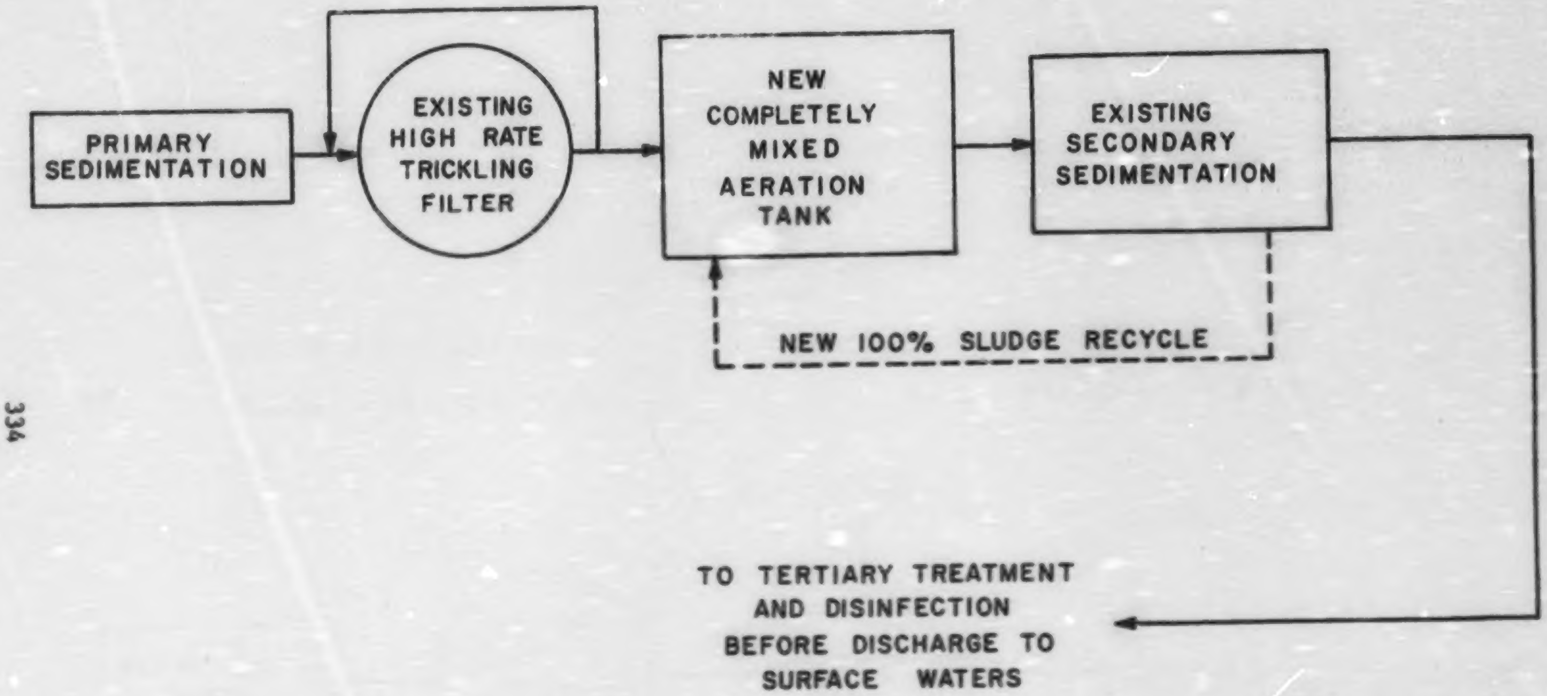

PRIMARY SEDIMENTATION
EXISTING HIGH RATE TRICKLING FILTER
NEW COMPLETELY MIXED AERATION TANK
EXISTING SECONDARY SEDIMENTATION
NEW 100% SLUDGE RECYCLE
TO TERTIARY TREATMENT AND DISINFECTION BEFORE DISCHARGE TO SURFACE WATERS

Figure VII-19. Trickling Filtration/Activated Sludge System

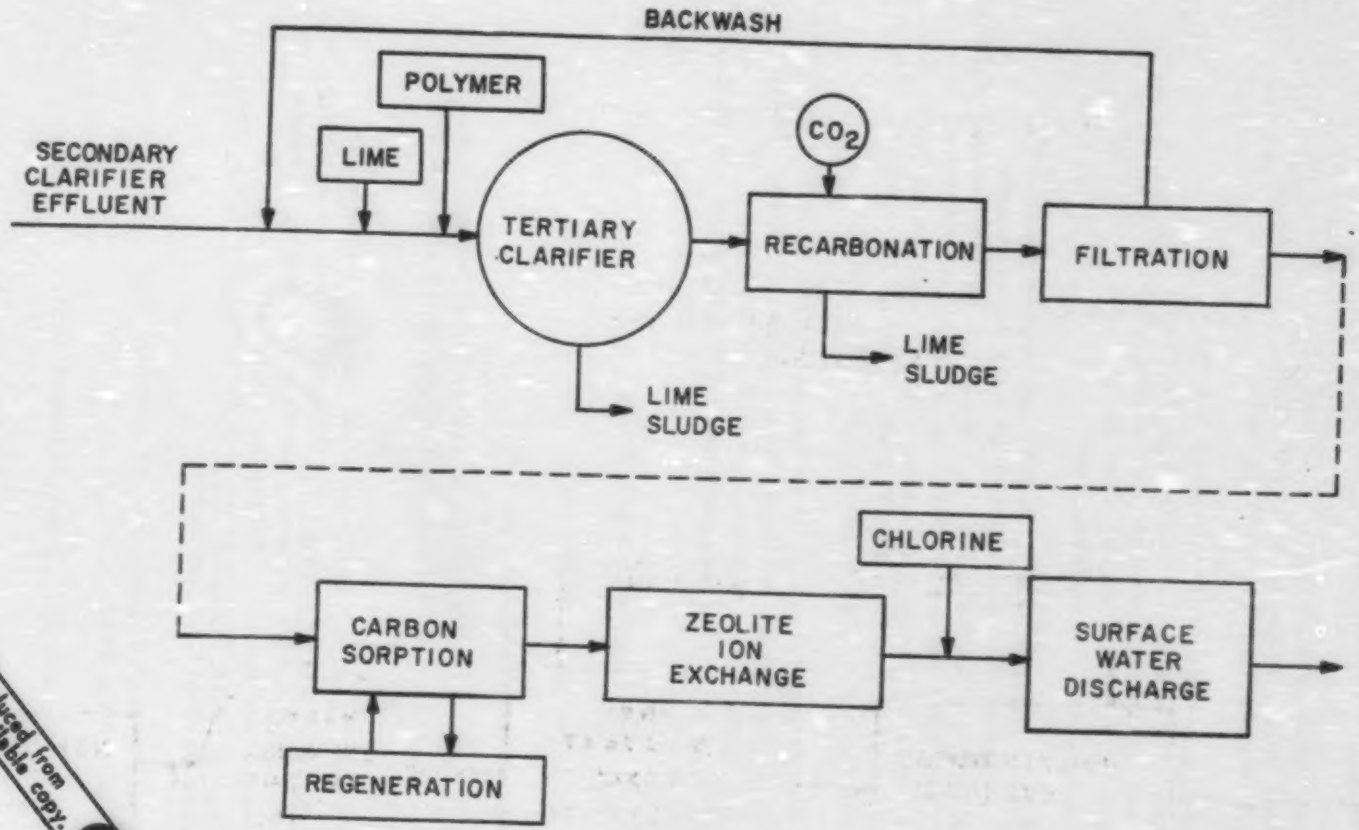

BACKWASH
POLYMER
LIME
SECONDARY CLARIFIER EFFLUENT
TERTIARY CLARIFIER
CO_2
RECARBONATION
FILTRATION
LIME SLUDGE
LIME SLUDGE
CHLORINE
CARBON SORPTION
ZEOLITE ION EXCHANGE
SURFACE WATER DISCHARGE
REGENERATION

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Figure VII-20. Added Tertiary Treatment Unit Processes, Incineration of Chemical Sludge

Northwest Laboratories.[19] Capital cost changes due to variations in plant size are approximated through use of the exponential rule:[19]

1. if plant size changes by a factor of X, the cost will change by a factor of X^N where N varies from 0.0 to 1.0, and

2. an average exponential factor of N = 0.6 is used, for wastewater treatment facilities and equipment designed for plants with 100 mgd (378,500 cu m/day) flow or less, as in the case for Des Moines, Iowa.

Capital costs presented in the Battelle Report are expressed in 1973 dollars (ENR=1900). Capital costs presented in this section have been updated by multiplying the base cost by the ratio of the current (1975) ENR index (2200) to the 1973 index. Local cost multipliers were not available to adjust national average costs to figures reflecting the price structure likely to prevail in Des Moines. Thus, for example, a land value of $1000 per acre ($2500 per ha) has been assumed.

Operating costs may vary significantly from the estimates provided in this section as a result of local differences in costs for power, fuel, chemicals, labor, transportation, supervision and maintenance. An exponential rule is used to adjust approximately for variations in plant size as follows:

1. N = 0.58 for labor and supervision,

2. N = 0.55 for electrical, and

3. N = 1.00 for chemicals and fuel,

for flow rates up to 100 mgd (378,500 cu m/day). Total annual costs are then calculated by adding amortized capital costs to the operating and maintenance costs.

Capital costs are shown itemized in Table VII-7, Capital Costs for Tertiary and Intermediate-Stage Treatment. These figures do not include costs of primary and secondary treatment, as they pertain to already existing conditions in Des Moines. Operating costs are listed in Table VII-8, Operating Costs for Tertiary and Intermediate-Stage Treatment. The following assumptions are made:

1. overall costs of labor are $8 per man hour for an 8 hour day,

2. power costs are $0.025 per kilowatt-hour,

TABLE VII-7. CAPITAL COSTS FOR TERTIARY AND INTERMEDIATE-STAGE TREATMENT, 35.3 MGD (1.55 cu m/sec)

Item	Base Cost[b]	Scale Factor,[a] X^N	ENR Ratio	Adjusted Cost
1. Liquid Treatment	\$4.7 x 10^6	$(3.53)^{0.6}$	$\frac{2200}{1900}$	\$11.60 x 10^6
2. Liquid Disposal	0.043 x 10^6	2.13	1.16	0.11 x 10^6
3. Chemical Sludge	1.9 x 10^6	2.13	1.16	4.69 x 10^6
4. Organic Sludge	1.0 x 10^6	2.13	1.16	2.47 x 10^6
Land for (1.)	12,000	2.13	1.16	0.03 x 10^6
(3.)	21,000	2.13	1.16	0.05 x 10^6
(4.)	4,100	2.13	1.16	0.01 x 10^6

TERTIARY CAPITAL EXPENDITURE	\$ 18,960,000
Intermediate-Stage Cost	+ 2,222,772
TOTAL CAPITAL EXPENDITURE	21,182,772

Amortization: 20 years at 8%

Amortized Annual Capital Cost =	\$2,157,508

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[a] See definition in text.

[b] Reference 19 (Strategy no. 9) for 10 mgd plant.

TABLE VII-8. OPERATING COSTS FOR TERTIARY AND INTERMEDIATE-STAGE TREATMENT, 35.3 MGD (1.55 cu m/sec)

Item	Base Cost[b]	Scale Factor,[a] X^N	Adjusted Cost
1. Base Labor		$3.53^{0.58}$	
(i) Liquid Treatment	214,912	2.08	$446,653/yr
(ii) Chemical Sludge	233,600	2.08	485,492
(iii) Organic Sludge	151,840	2.08	315,570
2. Electrical Power		$(3.53)^{0.55}$	
(i) Liquid Treatment	197,100	2.00	394,423
(ii) Chemical Sludge	29,337	2.00	58,707
(iii) Organic Sludge	16,516	2.00	33,051
3. Chemicals		$(3.53)^1$	
(i) Liquid Treatment			
a) Lime	153,300	3.53	541,149
b) CO_2	193,450	3.53	682,879
c) Cl_2	18,396	3.53	64,938
d) Polymer	15,330	3.53	54,115
(ii) Organic Sludge (Polymer)	146,000	3.53	515,380
4. Fuel		$(3.53)^1$	
(i) Liquid Treatment	3,164	3.53	12,756
(ii) Chemical Sludge	109,208	3.53	385,504
(iii) Organic Sludge	40,150	3.53	141,730
		TOTAL ANNUAL COST	$ 4,132,347

---

[a] See definition in text.

[b] Reference 19 (Strategy no. 9) for 10 mgd plant.

3. chlorine costs are $0.12 per pound ($0.26 per kg),

4. polymer costs are $2.00 per pound ($4.41 per kg),

5. lime costs are $0.02 per pound ($0.04 per kg),

6. CO_2 costs are $0.02 per pound ($0.04 per kg), and

7. fuel costs are $0.11 per therm ($0.11 per 1000 kg-calorie).

Transportation costs are not included since the sludge is assumed to be disposed on site by incineration. The total annual cost (including amortized capital cost) is $6,289,855. This figure represents a cost of $0.49 per 100[illegible] gallons ($0.13 per cu m) for conversion to activated sludge from high-rate trickling filtration, the intermediate-stage and addition of tertiary treatment with incineration of chemical and organic sludges.

The tertiary treatment configuration shown in Figure VII-20 constitutes a rather complete and sophisticated process profile. Battelle-Pacific Northwest Laboratories recommends this strategy as an alternative to existing secondary activated sludge plants which are required to provide additional organic and nutrient removal.[19] Furthermore, such a process configuration will produce a higher quality effluent than any of the other strategies considered.[19] However, examination of Tables VII-7 and VII-8 reveals that the incremental cost of providing such a facility is quite high. If organic waste removal is the primary consideration, a lower cost control strategy may be considered: activated sludge-coagulation-filtration (Battelle Northwest, 1974; Strategy 8).[19]

Assuming that the intermediate-stage conversion has been accomplished (see Figure VII-19), an alternative to complete tertiary treatment is shown in Figure VII-21, Activated Sludge-Coagulation-Filtration Process Profile. This control strategy compares favorably with the more advanced option in BOD removal capabilities. Treatment plant efficiencies vary considerably with the input flow rate and waste concentration. Battelle assumed a medium strength sewage of 200 mg/l.[19] For 10 mgd (38,000 cu m/day), 100 mgd (380,000 cu m/day) and 1000 mgd (3,800,000 cu m/day) plant sizes BOD removal efficiencies up to (1) 99 percent for tertiary treatment, and (2) 98 percent for activated sludge-coagulation-filtration are given.

In general terms, any type of post-secondary treatment (other than chlorine disinfection) is classified as tertiary treatment in the water pollution control literature. The option depicted by Figure VII-21 has been assumed as a type of tertiary treatment and exclusively referred to

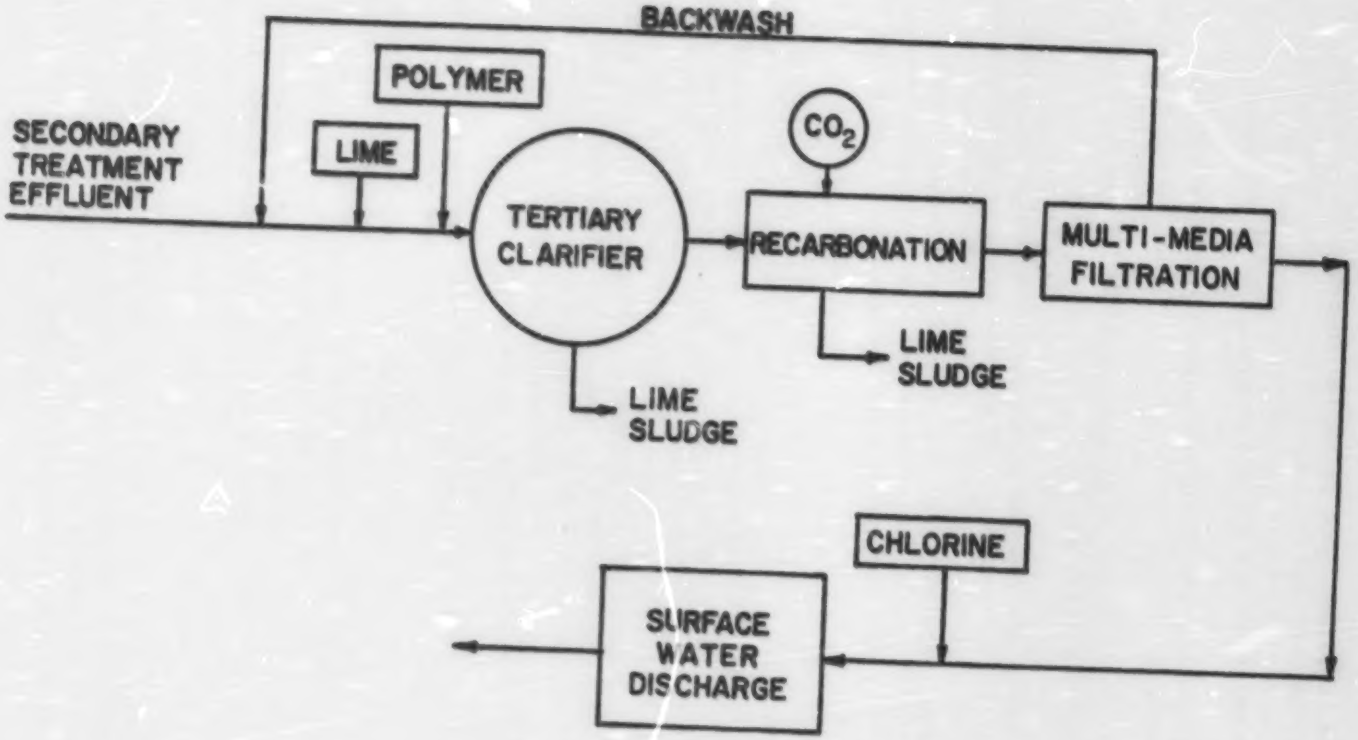
BACKWASH
POLYMER
LIME
SECONDARY
TREATMENT
EFFLUENT
TERTIARY
CLARIFIER
CO_2
RECARBONATION
MULTI-MEDIA
FILTRATION
LIME
SLUDGE
LIME
SLUDGE
CHLORINE
SURFACE
WATER
DISCHARGE

Figure VII-21. Activated Sludge-Coagulation-Filtration Process Profile

as such in the analysis presented in Section VI. The more descriptive title is used in this section to distinguish the process from the more advanced profile of Figure VII-20. It is appropriate to emphasize that the type of post-secondary DWF process adopted by a municipality will depend on such local factors as sewage characteristics, energy resources, and receiving water quality.

The incremental cost of providing the facilities of an activated sludge-coagulation-filtration system may be estimated by:[20]

$$C_{tert} = 87{,}000\ D_p^{0.787} \qquad \text{(VII-36)}$$

where C_{tert} = annual cost, dollars, including amortized capital costs (20 years, 8 percent) and operating and maintenance costs, and

D_p = plant size, mgd.

Total annual costs of both types of post-secondary treatment are summarized in Table VII-9, Dry-Weather Flow Costs for Advanced Treatment. The amortized capital cost of intermediate-stage conversion has been added to the cost computed by equation VII-36 for the activated sludge-coagulation-filtration design. The large difference in annual costs is due to:

1. the added expense for chemicals during ammonia removal, and

2. added fuel costs during incineration of chemical and organic sludges,

for the complete tertiary treatment configuration.

Control of Urban Runoff

The methodology for assessing the cost of providing storage/treatment facilities for wet-weather flows is presented in Section VI. A basic assumption is that a secondary treatment technology is applied to achieve four levels of control for the total BOD generated by urban runoff: 25, 50, 75 and 85 percent BOD removal. Various control alternatives were evaluated: dissolved air flotation, biological treatment, physical-chemical treatment and sedimentation.[21]

The cost of wet-weather control for the storm sewered area of Des Moines, Iowa, may be estimated by (Table VI-10):

$$Z_{ST} = 3.61\ e^{0.037R_1} \qquad \text{(VII-37)}$$

Table VII-9. DRY-WEATHER FLOW COSTS FOR ADVANCED TREATMENT[a]

Type	Total Annual Cost[b]
1. Complete Tertiary Treatment	$6,290,000
2. Activated Sludge-Coagulation-Filtration	$1,664,000

[a] For plant size 35.3 mgd (1.55 cu m/sec).

[b] Includes amortized capital costs, operating and maintenance costs, and intermediate-stage conversion.

Table VII-10. WET-WEATHER FLOW CONTROL COSTS[a]

R_1 % BOD Removal	Storm Sewer Area Cost, Z_{ST} \$/acre (\$/ha)	Combined Sewer Cost, Z_{CO} \$/acre (\$/ha)	Total Annual Cost
25[b]	9.10 (22)	101.66 (251)	$ 816,000
75[b]	57.90 (143)	1671.83 (4128)	$9,293,000

[a] Based on 49,000 acres (19,600 ha) of developed urban area.

[b] Approximate solution. See Section VI for details.

where Z_{ST} = annual cost, dollars per acre of storm sewer area, and

R_1 = percent BOD control,

and

$$0 \leq R_1 \leq 85. \qquad \text{(VII-38)}$$

The cost of wet-weather control for the urban area served by combined sewers may be approximated by (Table VI-9):

$$Z_{CO} = 25.07\, e^{0.056R_1} \qquad \text{(VII-39)}$$

where Z_{CO} = annual cost, dollars per acre of combined sewer area.

These equations yield unit costs, not total costs, but they are derived by a procedure that estimates the total developed acreage of an urban area (see Section VI). The average annual runoff associated with equations VII-37 and VII-39 is 11.2 inches (284 mm), computed from a mean annual precipitation of 30.37 inches (771 mm). The length of the precipitation records is 30 years (1931-1960).[22]

The cost figures for 25 percent and 75 percent BOD removal of WWF are presented in Table VII-10, Wet-Weather Flow Control Costs. These values are based on a total drainage area of 49,000 acres (19,600 ha), of which 45,000 acres (18,000 ha) are served by separate sewers and 4,000 acres (1,600 ha) are served by combined sewers. The annual runoff for 1968 for Des Moines, Iowa, is 10.28 inches (261 mm); thus, the unit costs obtained from equations VII-37 and VII-39 are slightly high but an adjustment is not considered necessary. The total annual costs shown in Table VII-10 include amortized capital costs and annual operating and maintenance costs.

Tradeoff in Alternatives

To view the control strategies in the proper perspective, the status quo conditions are included as a base for comparisons. Any alternative plans that depart from this base must be justified on their cost-effectiveness. Thus, the cost figures shown in Table VII-11, DWF Tertiary Treatment vs WWF Control, represent the additional expense incurred in providing storage/treatment beyond that already available with secondary treatment of DWF and no control of urban runoff. Figures VII-15, VII-16 and VII-17 show the effects of various control strategies upon the minimum DO concentrations of the Des Moines River.

Table VII-11. DWF TERTIARY TREATMENT VS WWF CONTROL

Options	Amortized Annual Capital Cost $ (20 yrs, 8%)	Operation and Maintenance Cost ($/yr)	Total Annual Cost ($/yr)
1. DWF Complete Tertiary Treatment, No WWF Treatment	2,158,000	4,132,000	6,290,000
2. DWF Activated Sludge-Coagulation-Filtration, No WWF Treatment	---	---	1,664,000
3. WWF 75% BOD Removal, DWF Secondary Treatment	---	---	9,293,000
4. WWF 25% BOD Removal, DWF Secondary Treatment	---	---	816,000

[a] Based on 49,000 acres (19,600 ha) of developed urban area. The total annual cost computed by equations VII-37 and VII-39 includes amortized capital cost (20 yrs, 8%) and operation and maintenance costs.

The Des Moines River stretches for 200 miles (322 km) from the City of Des Moines to its junction with the Mississippi River and, in general, the river is wide and swift with occasional deep holes and a broad flood plain. According to the State Hygienic Laboratory, bottom material is composed of silt deposits, sand, gravel and rubble providing numerous habitats for fish and other aquatic life. Recreational activities such as fishing and boating are quite heavy. The entire reach is classified as warm water "B" stream by the Iowa Water Quality Standards,[23] such that the absolute minimum dissolved oxygen level specified is 4.0 mg/l. The Iowa Standards also require a minimum of 5.0 mg/l during at least 16 hours per day.[24] Thus, taking 4.0 mg/l as the standard or basis for water quality comparisons, the different control options may be judged by the following criteria:

1. total annual cost, and
2. violations of the minimum allowable dissolved oxygen level.

Table VII-12, Control Costs vs Violations of the DO Standard, summarizes the cost-effectiveness of two advanced waste treatment options, two wet-weather control options, and existing DWF secondary treatment facilities. For comparative purposes, two additional treatment conditions which are not presently acceptable by government regulation are presented.

Examination of Figures VII-15, VII-16, VII-17 and Table VII-12 reveals that:

1. since both types of tertiary treatment remove essentially the same amount of BOD, option 1 is justified over option 2 only when nutrient removal is necessary;
2. option 4 is preferred over any form of advanced waste treatment;
3. option 3 is attractive because it causes the least amount of damage to the receiving stream, but it is the most expensive alternative; and
4. any reduction in the degree of DWF treatment for existing conditions, option 5, results in a substantial deterioration to receiving water dissolved oxygen levels and must be weighed against the savings incurred.

Table VII-12. CONTROL COSTS[a] VS VIOLATIONS OF DO STANDARD[b]

Options	% Wet-Weather Events[c] Violating Standard	% Dry Days in Year Violating Standard	Total Incremental Annual Cost ($/yr)	Total No. of Days During Year that DO Standard is Violated
1. DWF Complete Tertiary Treatment, No WWF Treatment	40	1.5	6,290,000	31
2. DWF Activated Sludge Coagulation-Filtration Treatment, No WWF Treatment	40	1.5	1,664,000	31
3. DWF Secondary Treatment, WWF 75% BOD Removal	3	2.0	9,293,000	8
4. DWF Secondary Treatment, WWF 25% BOD Removal	30	2.0	816,000	26
5. DWF Secondary Treatment, No WWF Treatment	42	2.0	0	33
6. DWF Primary Treatment, No WWF Treatment	50	3.0	-1,438,000[d]	42
7. No DWF Treatment, No WWF Treatment	53	7.0	-1,843,000[d]	55

[a] In addition to control costs for existing conditions (5).

[b] Based on a minimum allowable DO concentration of 4.0 mg/l.

[c] Defined by a minimum interevent time of 9 DWH.

[d] Savings incurred by reducing DWF treatment of trickling filter plant of 35.3 mgd (1.55 cu m/sec).

Again, the issue of shock loads is important, and favors high levels of WWF control.

The reader should be cautioned that advanced tertiary treatment is rarely imposed just to improve the BOD removal capabilities of existing facilities. It is usually designed specifically for nitrogen and/or phosphorus removal. For the heavy precipitation months of June, July and August, 1968, Davis and Borchardt[9] reported the following nutrient concentrations at a point approximately 5.5 miles (9.0 km) downstream from the confluence of the Raccoon and Des Moines Rivers:

1. total organic nitrogen ranged from 1.6 to 3.7 mg/l,
2. nitrate nitrogen ranged from 0.2 to 7.8 mg/l, averaging 3 to 4 mg/l, and
3. orthophosphate (OPO_4) ranged from 0.6 to 1.8 mg/l, averaging slightly over 1.0 mg/l.

Since most of the urban runoff would overflow untreated to the receiving water, any program of advanced treatment given to all urban DWF would be relatively ineffective. It would also be questionable whether a level of WWF control consisting of secondary treatment (such as that evaluated for 75 percent BOD removal) could reduce nutrient levels in the Des Moines River and Red Rock Reservoir to inhibit aquatic plant growth. Davis and Borchardt[9] observed high algal densities in both the Des Moines and Raccoon Rivers, and they also state that nutrient concentrations are almost always present at levels reported by Sawyer[25] to be sufficient for nuisance algal growths: 0.3 mg/l for inorganic nitrogen (NH_3, NO_2, NO_3) and 0.015 mg/l of inorganic phosphorus. Furthermore, since nitrates are abundant in groundwater and the surface and subsurface hydrologic systems are not independent of each other, nutrient control seems highly complex and improbable.[26]

The total annual precipitation for the year 1968 was 27.59 inches (701 mm). The frequency and intensity of precipitation over an urban area has a direct bearing on the magnitude of stormwater pollution and, consequently, dissolved oxygen levels in the receiving water. In the selection of the "best" control strategy, other factors may become important, such as:

1. recovery of receiving waters from shock loads during runoff periods,
2. local and regional water quality goals,
3. public willingness to pay the costs associated with each level of control, and

4. consideration of alternate use of WWF facilities as DWF treatment facilities during periods of no urban runoff.

In general, although selection of a storage/treatment configuration involves many factors it is important to note that the impact of urban stormwater runoff must be evaluated. Davis and Borchardt[9] compared daily pollutant loadings (BOD, NO_3, PO_4) from storms ranging in size from 0.175 inch (4.4 mm) to 6 inches (152.4 mm) in total depth to those from dry-weather sources in the Des Moines metropolitan area. In all cases, the loads derived from urban runoff exceeded greatly the average daily loads from dry-weather sources.

OTHER RECENT RECEIVING WATER IMPACT STUDIES

Black, Crow & Eidsness, Inc., and Jordan, Jones & Goulding, Inc., evaluated non-point pollution sources in the Atlanta metropolitan area and their impact on the dissolved oxygen (DO) levels in the Chattahoochee River.[27] Only two sources of urban stormwater runoff were reported as significant: combined sewer overflows and unsewered urban runoff (natural collection systems). On an annual basis, these sources accounted for about 45 percent of the BOD load (lbs/yr) and about 95 percent of the suspended solids load to metropolitan Atlanta streams, assuming that all point sources were receiving secondary treatment.

A steady-state mathematical model (developed by the Georgia Department of Natural Resources Environmental Protection Division) was applied to simulate the effects of a 0.4 inch (10.2 mm) rainstorm, with a two-hour duration of runoff, assumed to fall over all combined sewer overflow drainage areas.[27] It was also assumed that all point source (DWF) wastewater treatment plant effluents met state fish and wildlife standards. The results of the simulation indicate that such a rainstorm would violate stream DO standards in the Chattahoochee River for over 50 miles (80 km) downstream, with a minimum DO concentration of zero for a period of approximately 12 hours. The 0.4 inch rainstorm (upper limit of summer thunderstorm size in the Atlanta area) over any one of the combined sewer overflow areas would apparently cause a similar violation for a two-hour period. The impact of unsewered urban runoff on water quality in the Chattahoochee River was also determined by simulation of a rainfall event over the entire Peachtree Creek basin (highly urbanized). The storm selected was again 0.4 inch (10.2 mm) in rainfall volume but its duration was assumed to be 10 hours. The Corps of Engineers' model STORM was utilized to simulate the quantity and quality of the surface washoff. Output from STORM was routed down the Chattahoochee River using the model DOSAC (Texas Water Development Board).[31] Violations of the fish and wildlife standard, 5.0 mg/l of dissolved oxygen, were predicted for over 40 miles (64 km) downstream and the minimum dissolved oxygen concentration was computed to be 1.4 mg/l.

Hydrocomp International (Palo Alto, California) conducted dynamic simulation of a large watershed in the South Platte River basin for Black & Veatch and the Denver Regional Council of Governments.[28] The 750 square mile (194,256 ha) area included metropolitan Denver within its boundaries. Simulations of streamflow and stream water quality conditions for given precipitation, wastewater loadings, and diversions (irrigation) were performed for each of several proposed wastewater system configurations. The water quality calibration process to adapt the Hydrocomp Simulation Program (HSP) to actual environmental conditions was hindered by the lack of a continuous data base within the designated study area, a problem prevalent throughout the nation. An analysis of a 20-year simulation for one plant configuration indicated that the calendar year 1954 represented one of the most critical periods from a water quality standpoint. It had the lowest annual streamflow for the 20-year historical record, and some of the lowest stream dissolved oxygen concentrations were predicted.

The Hydrocomp study did not specifically address urban stormwater control facilities as a treatment alternative. Five levels of wastewater treatment (DWF) were tested for the critical year: (1) secondary, (2) secondary with filtration, (3) secondary with nitrification, (4) tertiary and (5) zero pollutants discharged. Daily duration curves were computed for minimum dissolved oxygen for each DWF treatment level. Of the five levels, the effluents from secondary treatment with nitrification, tertiary treatment, and absolute treatment (zero pollutant discharge from DWF sources, financially prohibitive) did not exceed the stream standards imposed by the regulatory agency. Treatment levels 3 and 4 were thus considered the only acceptable options from an effluent viewpoint. Three possible treatment plant discharge configurations were tested at these two treatment levels. The resulting minimum daily DO duration curves (such as Figure VII-6) were practically identical.

From the DO duration curves for zero pollutant discharge from dry-weather sources, some interesting inferences may be drawn on the effects of urban runoff. The average annual precipitation over the study area for the period 1935-1974, was 14.58 inches (370 mm), less than half the national average.[29] The entire modeling area may be classified as semi-arid. The total annual precipitation for the critical year 1954 was 7.51 inches (190 mm), or about one-fourth of the total annual precipitation recorded in 1968 over Des Moines, Iowa. The minimum daily DO duration curve for the zero pollutant discharge (DWF) treatment level was entirely above the minimum DO standard, 5.0 mg/l, for the reach of the South Platte River below the Denver metropolitan area. This curve represents the minimum daily DO concentration history of the receiving stream resulting exclusively from the urban runoff waste input. Thus, the urban runoff pollutant load for the drought year 1954 was insufficient to drive the critical DO levels below the fish and wildlife standard. The cost of stormwater control would not be justified.

Hydrocomp also prepared an evaluation of the effects of urbanization on aquatic ecology and hydrologic regimes for the Office of Water Research and Technology, Department of the Interior.[30] Urbanization affects flood frequency, flow duration, total volume of runoff, and has an impact because of additional pollutant load on stream BOD, DO, and nutrient concentrations. Computer simulation was employed to generate synthetic data series in the absence of historic series for three hypothetical cities representing the Pacific Northwest, eastern slope of the Rocky Mountains, and the central Atlantic states. Of particular interest is a comparison among these regions of the effect of urbanization on: (1) surface runoff quantity (Table VII-13, Increase in Surface Runoff), and (2) pollutant loadings (Table VII-14, Increase in Annual BOD Mass Discharge). The hypothetical watersheds consisted of a drainage area of 60 square miles (155.4 sq km) having all of the land surface characteristics of the test watersheds (for which HSP was regionally calibrated), including impervious area. For the urbanized case, the lower half of each watershed was assumed to be intensively urbanized with 35 percent imperviousness and directly connected to the stream system. The hydrologic period of study extended from 1948 to 1972. The average percent increase of annual runoff due to urbanization was much greater for the arid watershed. For the very wet watershed, the Pacific Northwest, high soil moistures resulted in almost as much runoff from rural land as from impervious (urban) areas. A substantial increase in peak flows was observed for one year return period events. Again, the percentage increase in peak flows due to increased imperviousness was observed to decrease from arid to wet regions. For the 25-year peak flows, the percent increase due to urbanization was slight. This, of course, is largely due to the magnitude of these events. It is interesting to note from Table VII-14 that the annual BOD mass discharge was increased at least 100 percent by urbanization.

CONCLUSIONS

A methodology has been presented in Section VII to assess the relative importance of separate, combined, and DWF sewer runoff as waste sources generated by the urban environment. The effects of WWF and DWF pollutants on the minimum DO levels of an urban stream are presented on a frequency basis. The application to Des Moines, Iowa, demonstrated clearly the significant effect of urban runoff pollution on critical DO concentrations in the Des Moines River. The cost-effectiveness of various wastewater treatment alternatives can be determined realistically only by a continuous model which shows the frequency of water quality violations in the receiving stream.

Table VII-13. INCREASE IN SURFACE RUNOFF (Hydrocomp, 1975)[30]

Basin	Mean Annual Precipitation in (mm)	% Increase Annual Runoff	% Increase Peak Flows 1 yr-25 yr
Eastern Slope Rocky Mountains	18.2 (462.0)	91	2800 - 9
Central Atlantic	43.5 (1105.0)	53	1460 - 4
Pacific Northwest . .	56.2 (1427.0)	10	1200 - 1

Table VII-14. INCREASE IN ANNUAL BOD MASS DISCHARGE (Hydrocomp, 1975)[30]

Basin	Rural BOD lbs/yr (kg/yr)	Urban BOD lbs/yr (kg/yr)	Urban/Rural Ratio
Eastern Slope Rocky Mountains	0.65×10^5 (0.29×10^5)	2.1×10^5 (0.95×10^5)	3.2
Central Atlantic	1.30×10^5 (0.59×10^5)	3.0×10^5 (1.36×10^5)	2.3
Pacific Northwest	2.10×10^5 (0.95×10^5)	4.4×10^5 (2.00×10^5)	2.1

For 1968, 65 days of rainfall were recorded over Des Moines, Iowa, from which 58 wet-weather events were defined according to a minimum interevent time of nine dry-weather hours. The annual precipitation total was 27.59 inches (701 mm), producing 10.28 inches (261 mm) of urban runoff. For existing treatment facilities, 42 percent of the wet-weather events were predicted to violate a 4.0 mg/l DO standard, as well as two percent of all the dry-weather days. Thus, the model predicted that violations of such a standard would occur 33 days out of the year. The highest control strategy would reduce the number of days to eight, at an incremental cost of $9 million. The most cost-effective alternative seems to be 25 percent control of WWF and secondary treatment of DWF, at a cost of $816,000 per year, and resulting in stream standard violations 26 days out of the year.

The methodology that has been applied to the Des Moines urban area should serve as a decision-making tool for planning purposes only. Other models exist that are better suited for the intent of design and operation. In spite of the use of simplified mathematical modeling techniques, close agreement was achieved with field measured data through verification analysis, and the primary purpose of the modeling effort was accomplished. The reader should review the numerous assumptions which were an integral part of model development and application and should understand that the final numbers obtained are intended as a guide for screening alternatives.

ABBREVIATIONS AND SYMBOLS

A_c	Area served by combined sewers, acres
A_s	Area served by separate sewers, acres
A_t	Total area of catchment, acres
AR_u	Urban area runoff, inches per hour
α_1,α_2	Regression coefficients
B	Benthal demand of bottom deposits, mg per 1-hour
BOD	Biochemical oxygen demand, mg/l
BOD_5	Standard BOD test, 5 days at 68°F (20°C), mg/l
BOD_c	Mixed BOD concentration in the combined sewer, mg/l
BOD_d	BOD concentration of wet-weather flow treatment facility effluent, mg/l
BOD_f	BOD concentration of municipal sewage, mg/l
BOD_m	Mixed BOD concentration in receiving water, mg/l
BOD_s	BOD concentration of urban stormwater runoff, mg/l
BOD_t	Hourly BOD concentration of total urban runoff, mg/l
BOD_u	Mixed BOD concentration from sources upstream of urban area, mg/l
BOD_w	BOD concentration of treated wet-weather effluent, mg/l
β_1,β_2	Regression coefficients
C	Concentration of water quality parameter, M/L^3
C	Concentration of dissolved oxygen (DO) in the stream, mg/l
C_{min}	Concentration of DO at maximum deficit, mg/l
C_s	Saturation concentration of DO, mg/l
C_1	Conversion factor, pounds per hour to mg/l · cfs
C_{tert}	Annual cost of activated sludge-coagulation-filtration system, dollars
CBOD	Carbonaceous biochemical oxygen demand

COD	Chemical oxygen demand
CR_u	Composite runoff coefficient dependent on urban land use
D	Dissolved oxygen deficit $= C_s - C$, mg/l
D_c	Critical (maximum) deficit, mg/l
D_u	DO deficit in receiving waters upstream of inflow point, mg/l
D_o	Initial DO deficit, mg/l
D_p	Size of activated sludge-coagulation-filtration plant, mgd
DO	Dissolved oxygen
DWF	Dry weather flow, cfs
DWFSEP	Dry-weather flow contribution from separate sewer area, cfs
DWFCMB	DWF contribution from combined sewer area, cfs
DWH	Number of dry-weather hours preceding each runoff event
E	Longitudinal dispersion coefficient, feet^2 per second
ENR	Engineering News Record Cost Index
f	Self-purification ratio, K_2/K_1
f_u	Available urban depression storage, inches
FF	First flush BOD load, pounds per hour
FFLBS	First flush factor, pounds/hour per DWH-acre
H	Stream depth, feet
k	Number of hourly lags
K_n	Oxidation coefficient of nitrogenous BOD, hours^{-1}
K_1	Deoxygenation constant of carbonaceous BOD, hours^{-1}
K_2	Atmospheric reaeration coefficient, hours^{-1}
L	Remaining carbonaceous BOD concentration, mg/l
L_o	Mixed BOD concentration in the river, mg/l
$(L_o)_c$	Ultimate first-stage BOD demand, mg/l

n	Total number of data points or observations of a hydrologic process
N_n	Remaining nitrogenous BOD concentration, mg/l
N	Exponent in scale factor
NBOD	Nitrogenous biochemical oxygen demand
OPO_4	Orthophosphate
P	Oxygen production rate by algal photosynthesis, mg/l-hour
P_u	Hourly rainfall/snowmelt in inches over the urban area
Q	Streamflow, cfs
Q_c	Combined sewer flow, cfs
Q_d	DWF treated effluent, cfs
Q_s	Urban runoff carried by the separate storm sewer, cfs
Q_t	Total (storm plus combined) urban runoff, cfs
Q_u	Upstream flow, cfs
Q_w	Wet-weather flow (WWF) treated effluent, cfs
R_1	Percent BOD control (removal) by wet-weather storage-treatment
R_d	Fraction removal of BOD achieved by the DWF treatment facility
R_e	Algal respiration rate, mg/l-hour
$r_I(k)$	Sample estimate of lag-k autocorrelation coefficient for rainfall
R_o	Deficit load ratio = D_o/L_o
$r_Q(k)$	Sample estimate of lag-k autocorrelation coefficient for runoff
R_w	Fraction removal of BOD achieved by the WWF treatment facility
S	Sources and sinks of the substance C, M/L^3T
T	Stream temperature, °C
t	Time, hours or days
t_c	Elapsed time at which critical deficit occurs, hours or days

TL(95%)	Tolerance limits at a 95 percent probability level
TOC	Total organic carbon
TSS	Total suspended solids
U	Flow velocity in stream, feet per second
V̶	Volume of DO deficit, mg-hours/l or mg-day/l
WWF	Wet-weather flow, cfs
x	Distance downstream, feet or miles
x_1	Discrete data series (observations) of a hydrologic process
X	Scale factor
Z_{CO}	Optimal annual cost of wet-weather control for combined sewered areas, dollars per acre
Z_{ST}	Optimal annual cost of wet-weather control for storm sewered areas, dollars per acre

REFERENCES

1. Geraghty, J. J., et al., Water Atlas of the United States, Water Information Center, Inc., Port Washington, NY, 1973.

2. Murray, C. R. and Reeves, E. B., "Estimated Use of Water in the United States in 1970," USGS Circular 676, 1972.

3. US Department of Agriculture, "Major Uses of Land and Water in the United States with Special Reference to Agriculture: Summary for 1964," Econ. Rept. 149, 1968.

4. Medina, M. A., Jr., "Data Needs for Stormwater Treatment and Control," Proceedings of Third Annual Environmental Short Course, Florida Engineering Society, Lake Buena Vista, Florida, October, 1974.

5. Liptak, Bela G., Environmental Engineers' Handbook, Vol. 1: Water Pollution, Section 2.10, Chilton Book Company, Radnor, PA, 1974.

6. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 13th Edition, Washington, DC, 1971.

7. Nemerow, N. L., Scientific Stream Pollution Analysis, McGraw-Hill Book Company, NY, 1974.

8. Hydrologic Engineering Center, Corps of Engineers, "Urban Stormwater Runoff: STORM," Generalized Computer Program 723-58-L2520, 1975.

9. Davis, P. L. and Borchardt, F., "Combined Sewer Overflow Abatement Plan," USEPA Report EPA-R2-73-170, April, 1974.

10. Yevjevich, V., Stochastic Processes in Hydrology, Water Resources Publications, Fort Collins, CO, 1972.

11. Fiering, M. B. and Jackson, B. B., Synthetic Streamflows, Water Resources Monograph 1, American Geophysical Union, Washington, DC, 1971.

12. Quimpo, R. G., "Autocorrelation and Spectral Analyses in Hydrology," J. Hyd. Div., Proc. ASCE, Vol. 94, No. HY2, pp. 363-373, March 1968.

13. Hydroscience, Inc., "Simplified Mathematical Modeling of Water Quality," USEPA, March 1971.

14. ASCE, Committee on Sanitary Engineering Research, "Solubility of Atmospheric Oxygen in Water," JSE Div., Proc. ASCE, Vol. 86, No. SA4, pp. 41-53, July 1960.

15. Langbein, W. B. and Durum, W. H., "The Aeration Capacity of Streams," USGS Circular 542, 1967.

16. Leopold, L. B. and Maddock, T., "The Hydraulic Geometry of Stream Channels and Some Physiographic Implications," USGS Professional Paper 252, 1953.

17. Arbabi, M. *et al.*, "The Oxygen Sag Equation: New Properties and a Linear Equation for the Critical Deficit," Water Resources Research, Vol. 10, No. 5, pp. 921-929, October 1971.

18. Krishnan, P. and Mangan, C. M., Roy F. Weston, Inc., "Process Design Manual for Upgrading Existing Wastewater Treatment Plants," USEPA Technology Transfer, October 1971.

19. Battelle-Pacific Northwest Laboratories, "Evaluation of Municipal Sewage Treatment Alternatives," Council of Environmental Quality, NTIS-PB 233 489, February 1974.

20. Hasan, S. M., Integrated Strategies for Urban Water Quality Management, PhD Dissertation, University of Florida, Gainesville, 1976.

21. Lager, J. A. and Smith, W. G., "Urban Stormwater Management and Technology: An Assessment," USEPA Report EPA-670/2-74-040, NTIS-PB 240 687/AS, December 1974.

22. Waite, P. J., "The Climate of Iowa," *Climates of the States*, Vol. II, Water Information Center, Inc., Port Washington, NY, 1974.

23. State Hygienic Laboratory, "Des Moines River - Limnology Study," Report submitted to the Department of Environmental Quality and the Iowa Water Quality Commission, April 1974.

24. State Hygienic Laboratory, "Water Quality Survey of the Des Moines River," Report submitted to the Iowa Pollution Control Commission, October 1970.

25. Sawyer, C. N., "Basic Concepts of Eutrophication," JWPCF, Vol. 38, No. 5, pp. 737-744, May 1966.

26. Sawyer, C. N., "The Need for Nutrient Control," JWPCF, Vol. 40, No. 3, pp. 363-370, March 1968.

27. Black, Crow & Eidsness, Inc. and Jordan, Jones & Goulding, Inc., "Non Point Pollution Evaluation - Atlanta Urban Area," Report to US Army Corps of Engineers, Savannah District, GA, January 1975.

28. Black and Veatch, "Volume II -- Hydro Quality Model Report, " Denver Regional Council of Governments, Water Quality Management Program Project No. IGA-00034, May 1974.

29. Private Communication, National Oceanic and Atmospheric Administration, Asheville, NC, September 1975.

30. Hydrocomp, Inc., "Evaluation of the Effects of Urbanization on Aquatic Ecology and Hydrologic Regimes," Office of Water Research and Technology, Contract No. 14-31-001-4203, July 1975.

31. Texas Water Development Board, "DOSAG-I Simulation of Water Quality in Streams and Canals, Program Documentation and User's Manual," Austin, Texas, NTIS-PB 202 974, September 1970.

SECTION VIII

GLOSSARY

Antecedent conditions--Initial conditions in catchment as determined from hydrologic events prior to storm.

Biological treatment processes--Means of treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Trickling filters, activated sludge processes, and lagoons are examples.

Catchment--Surface drainage area.

Combined sewage--Sewage containing both domestic sewage and surface water or stormwater, with or without industrial wastes. Includes flow in heavily infiltrated sanitary sewer systems as well as combined sewer systems.

Combined sewer--A sewer receiving both intercepted surface runoff and municipal sewage.

Combined sewer overflow--Flow from a combined sewer in excess of the interceptor capacity that is discharged into a receiving water.

Conservative--Non-interacting substance, undergoing no kinetic reaction; examples are salinity, total dissolved solids, total nitrogen, total phosphorus.

Convective Precipitation--Precipitation caused by lifting due to convective currents, as in thunderstorms.

Cyclonic Precipitation--Precipitation caused by lifting associated with junctions of different air masses, as for instance, with most warm and cold fronts.

Depression Storage--Amount of precipitation which can fall on an area without causing runoff.

Detention--The slowing, dampening, or attenuating of flows either entering the sewer system or within the sewer system by temporarily holding the water on a surface area, in a storage basin, or within the sewer itself.

Domestic sewage--Sewage derived principally from dwellings, business buildings, institutions, and the like. It may or may not contain groundwater.

Economies of scale--Unit costs decrease as output increases.

Equalization--The averaging (or method for averaging) of variations in flow and composition of a liquid.

Expansion path--Locus of points connecting numerous isoquants indicating the optimal combination of inputs.

First flush--The condition, often occurring in storm sewer discharges and combined sewer overflows, in which a disproportionately high pollutional load is carried in the first portion of the discharge or overflow.

Frequency diagram--Curve which relates the number of occurences of events to their magnitude.

Initial abstraction--Initial precipitation loss including interception and depression storage.

In-system--Within the physical confines of the sewer pipe network.

Interception--Initial lost of precipitation due to vegetation.

Isocost Lines--Lines of equal cost.

Isoquants--Curves representing combinations of the inputs yielding the same amount of output.

Non-conservative--substance undergoing kinetic interaction, assumed to be a first-order reaction; examples are biochemical oxygen demand (BOD), coliform bacteria, dissolved oxygen (DO).

Orographic Precipitation--Precipitation caused by lifting of an air mass over mountains.

Orthophospate--Phosphate that appears as $PO_4^{=}$, HPO_4^{-} or H_2PO_4, i.e. is hydrolizable. Creates a growth response in algae.

Physical-chemical treatment processes--Means of treatment in which the removal of pollutants is brought about primarily by chemical clarification in conjunction with physical processes. The process string generally includes preliminary treatment, chemical clarification, filtration, carbon adsorption, and disinfection.

Pollutant--Any harmful or objectionable material in, or change in, physical characteristic of water or sewage.

Precipitation event--A precipitation event terminates if zero rainfall has been recorded for the previous specified time interval.

Primary treatment--Process which removes about 35% of the biochemical oxygen demand of the waste.

Retention--The prevention of runoff from entering the sewer system by storing on a surface area or in a storage basis.

Runoff coefficient--Fraction of rainfall that appears as runoff after subtracting depression storage and interception. Typically accounts for infiltration into ground and evaporation.

Sanitary sewer--A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with relatively low quantities of ground, storm, and surface waters that are not admitted intentionally.

Secondary treatment--Process which removes about 85% of the biochemical oxygen demand of the waste.

Sewer--A pipe or conduit generally closed, but normally not flowing full, for carrying sewage or other waste liquids.

Sewerage--System of piping, with appurtenances, for collecting and conveying wastewaters from source to discharge.

Storm flow--Overland flow, sewer flow, or receiving stream flow caused totally or partially by surface runoff or snowmelt.

Storm sewer--A sewer that carries intercepted surface runoff, street wash and other wash waters, or drainage, but excludes domestic sewage and industrial wastes.

Storm sewer discharge--Flow from a storm sewer that is discharged into a receiving water.

Stormwater--Water resulting from precipitation which either percolates into the soil, runs off freely from the surface, or is captured by storm sewer, combined sewer, and to a limited degree,sanitary sewer facilities.

Surface runoff--Precipitation that falls onto the surfaces of roofs, streets, ground, etc., and is not absorbed or retained by that surface, thereby collecting and running off.

Tertiary treatment--Process which removes about 96% of the biochemical oxygen demand of the waste.

Urbanized area--Central city, or cities, and surrounding closely settled territory. Central city (cities) has population of 50,000 or more. Peripheral areas with population density of 1,000 persons per acre or more are included.

Urban runoff--Surface runoff from an urban drainage area that reaches a stream or other body of water or a sewer.

Wastewater--The spent water of a community.